Study and tests of a discrete readout electronic system for the R7600-00-M4 photomultiplier tube used on the calorimeter in the AMS02 experiment

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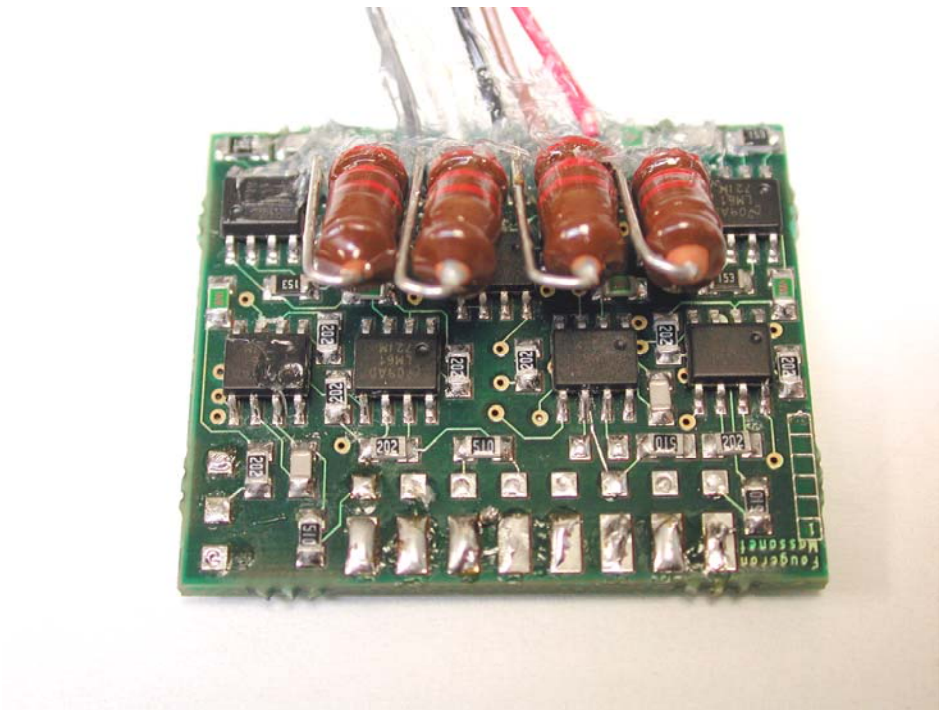

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Introduction:

As part of the AMS02 experiment, a study was conducted on a discrete electronic system in parallel with the design of the ASIC Front End to be used in the readout chain of the Hamamatsu 4-anode R7600-00-M4 **P**hoto**M**ultiplier tube(PM).

The purpose of this electronic system is to shape a fast analog signal of a PM primarily with passives components.
First idea is to create a shaper without amplifier, in order to reduce the power consumption.

The photomultiplier has been characterized to remain within a large dynamic range of output signals we wish to measure. The use of the PM is somewhat different from specifications presented in the data sheet (cf. appendix 3):

- Anodes will not be loaded at 50 Ω, but at a much higher impedance. We must preserve the signal integrity and measure some low amplitude signals.

- Hamamatsu suggests various ways to distribute the high voltage. The dynode polarization chain has been chosen to get a wide dynamic range and to keep signal's linearity.

- PM works with a gain value around $G = 10^5$ with 650 Volts for high voltage power supply. This values have been chosen in accordance with the energy range of particles detected in the calorimeter.

The saturation limit measured under these conditions corresponds to a 2nC signal charge.
For a 20ns time width, the peak current delivered by the PM is 100mA. The rate frequency is around 1kHz.
All signals have been measured with these parameters.

First we defined signal shaping. Then, we looked for an amplifier with a great rapidity/consumption ratio to drive analog input of a Lecroy 2249 ADC, often used in the laboratory.

1-Schematic's specification:

Schematic:

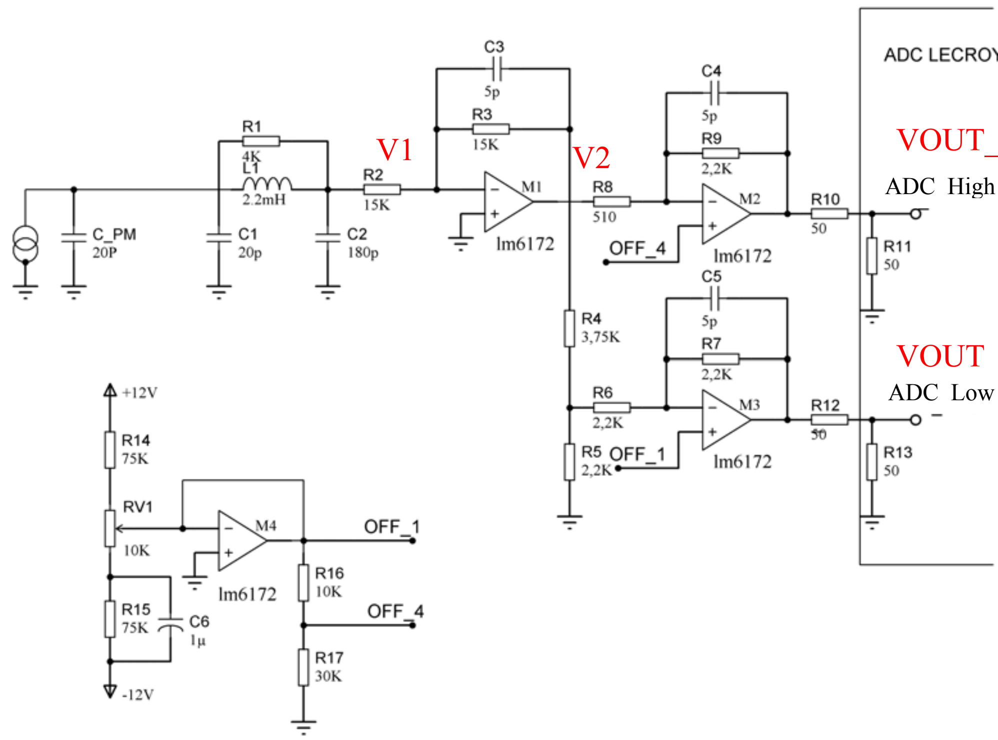


Figure 1 - Electronic readout schematic per channel

The photomultiplier is schematically represented by an electrical generator associated with a C_PM = 20pF parasitic capacitor measured using an impedance meter.

The signal from a PM is a fast signal with a few nanoseconds rise time.
The electronic system's aim associated with the PM is to delay this signal for at least two main reasons:

- Active components have been chosen to reduce the $\dfrac{rapidity}{consumption}$ ratio. If the input analog signal have a slow rise time, electronic system needs a low current supply.

- To integrate this electronic in a read-out chain, the chain will be synchronized using a external scintillator that will necessarily be later than the particle signal. So we need a signal reaction time that is more greater than the experiment triggering time.

The analog signal is shaped by the first stage of the schematic.
This stage consists in a passive damped RLC circuit calculated primarily through a simulation. By this, it's possible to restitute a current signal on the R2 resistor that was proportional to the input charge.
This signal is shaped with a rising time of a few hundred nanoseconds. Yet it has a peak voltage that enables the M1 amplifier to operate in linear mode. (Cf. figures 3 and 4, "LM6172 in follower mounting".)
Amplifiers selected are powered with +/- 12 V in order to enlarge the dynamic range that we have chosen (Dynamic = 10000).
For this dynamic range, we need two ADC's channels and two different gains must be used, so that small signals of about 0.25pC can be amplified and detected.
In addition, the M4 amplifier used as a follower purposely generates offset. We added a pedestal so that the signal lies in the range of 0 to –1 Volt. This pedestal has the same sign as the signal and a low value.
This method provides a reference with respect to signal amplitude.

The ADC has a 50 Ω input load to this value so that the signal is not distorted. We have inserted a 50 Ω resistor to reduce by two the amplitude at the ADC input.

Summary:

Initial parameters:

Dynamic range = 10000
No. bits = 10 (ADC 2249A)
ADC input voltage = 1V full scale
Emax = 10V (cf. note on amplifier below)

$$LSB = \frac{1V}{2^{NbBits}} = \frac{1}{1024} = 1\text{mV}$$

$$E\min \times Gain = 2 \times LSB \Leftrightarrow \frac{E\max}{Dynamic} \times Gain = 2 \times LSB$$

Thus the product $E\max \times Gain = 2 \times 1mV \times 10000 = 20$

Amplifier saturation voltage is about 10V:
Gain in the "small signal" channel $\Rightarrow G = \frac{20}{E\max} = \frac{20}{10} = 2$
A gain of 4 has been chosen because we will then divide by 2. This is necessary because of the 50Ω charge required by the ADC.

For the second, "strong signal" range, we attenuate by:

$$\text{Att} = \frac{10V}{1V} = 10$$

An attenuation of 5 is chosen because we will then divide by 2 as a result of the ADC input charge.

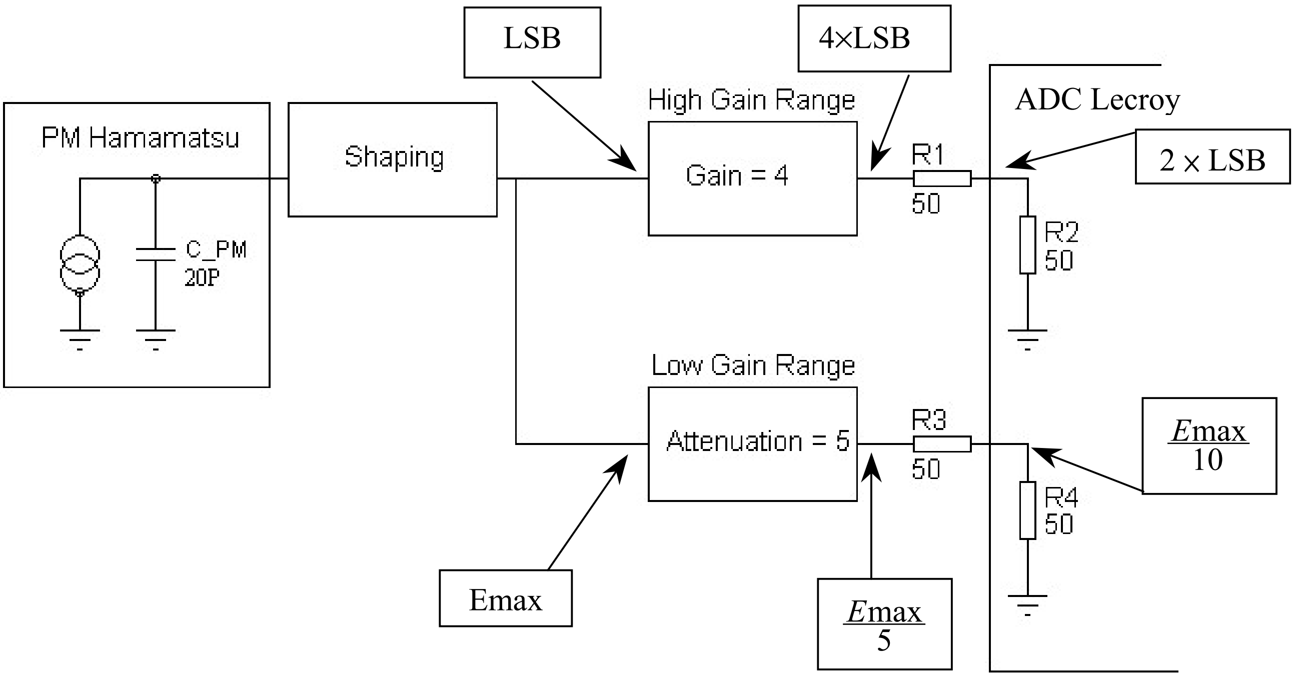


Figure 2 - Synoptic diagram of the electronic system per pixel

ADC:

The ADC used is a Lecroy ADC that is in fact a charge ADC. It is not the best suited to this type of application.
Although it requires some effort to measure a peak voltage, we were able to evaluate the linearity and dynamic of the circuit using this equipment. In addition, the data acquisition system associated with this ADC was already set up and ready to use.

Model	2249A	2249W
No. of channels	12	12
No. of bits	10	11
Analog inputs	Direct coupled, 50Ω, linear range from –2mV to - 1V	AC coupled, 50Ω, linear range from 0 to -2V
Scale	-256pC +/-5%	-512pC +/-5%
Resolution	-0.25pC	-0.25pC
Gate (duration)	50Ω, duration of 10ns to 200ns	50Ω, duration of 30ns to 10µs

Table 1 – ADC's characteristics

Amplifier: LM6172 (National Semiconductor)
The LM6172 amplifier has chosen.

Parameters	Typical value	Units
Power supply	$5.5 \leq Vs \leq 36$	Volt
Input current (per amplifier)	1.2	µA
Supply current (per amplifier)	2.3	mA
Slew Rate	3000	V/µs
Bandwidth (Unit gain)	100	MHz
Output current (per amplifier)	50	mA
Output resistance	14	Ω

Case	Reference No.
DIP 8	LM6172IN

Table 2 – Amplifier's characteristics

LM6172 in follower mounting:

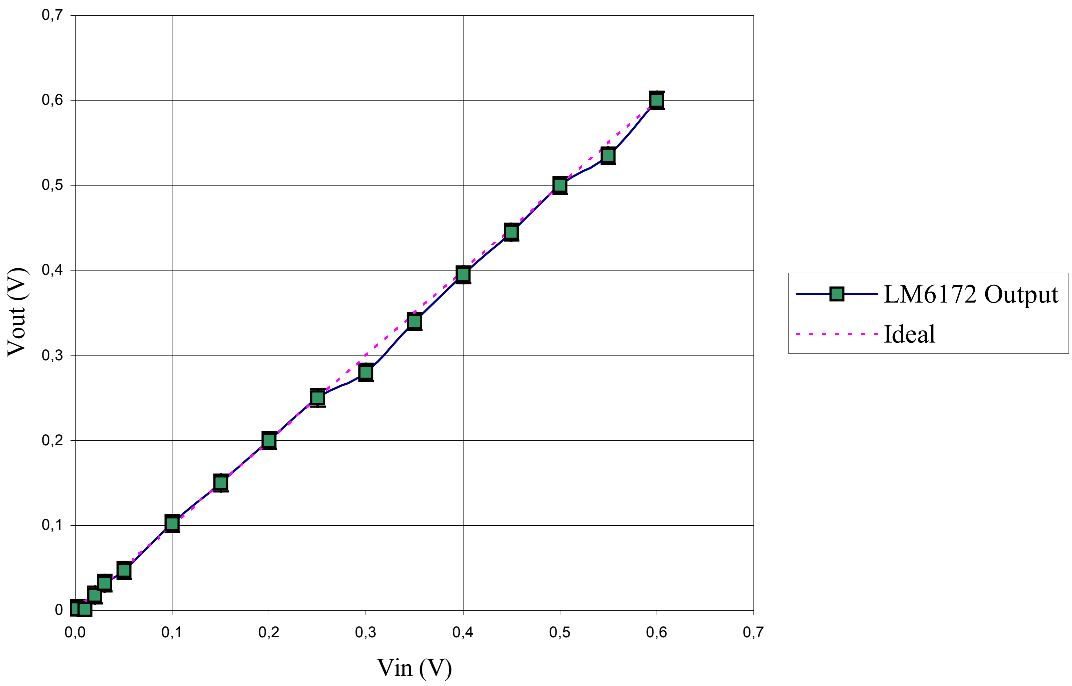


Figure 3 - LM6172 amplifier follower (small signals)

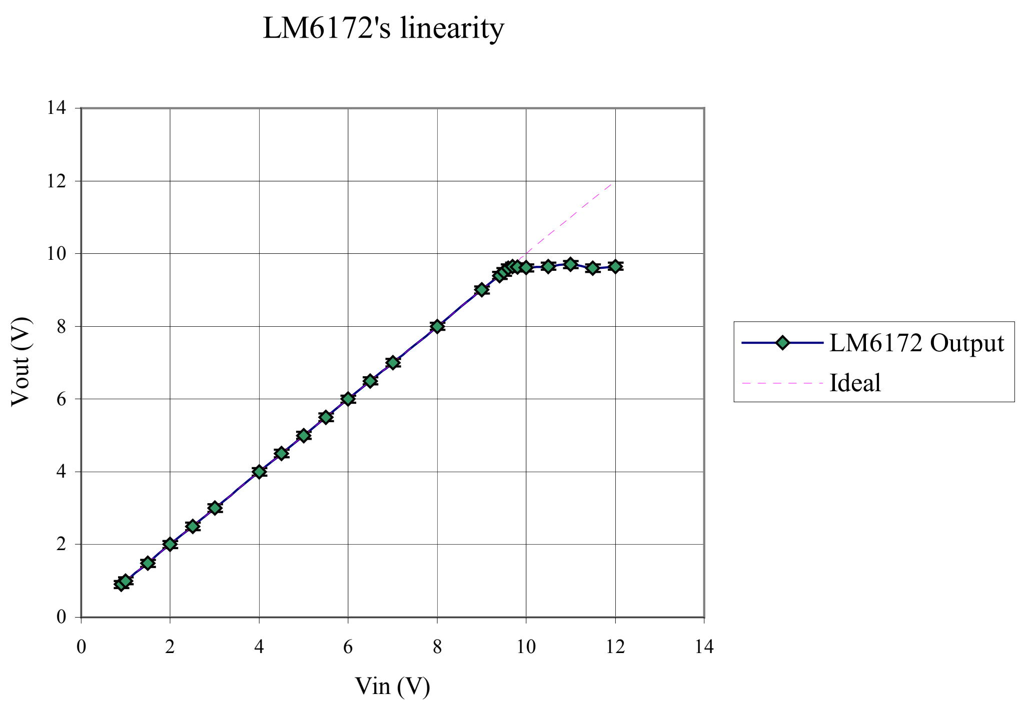


Figure 4 - LM6172 amplifier follower (large signals)

The LM6172 amplifier correctly follows the input signal. Its spice macromodel is reliable given the measures obtained. The amplifier is not limited by its slew rate, either for small signals or for signals up to voltage supply. Its saturation voltage is approximately 9.6V. Gains shall be adjusted according to this value.

The delay caused by the amplification channel is around 60ns. If two amplifiers are connecting in series, there is a total delay of about 100ns. This parameter must be taken into account and added to define total peaking time.
This amplifier has been chosen for its consumption (2.5 mA per amplifier). It is a good compromise compared to other amplifiers.
It must also support a 50 Ω load, and so its output stage must to provide the electrical power.

Power consumption:

For each anode, four amplifiers are supplying with +/- 12 Volt power supply. Three amplifiers for two ranges plus one for the offset. To avoid interfering with the output amplifiers, and in particular for peaking time values, we introduced an additional follower amplifier (M4) to adjust impedance.

Consumption per pixel:

$$\mathrm{P} = \mathrm{Voltage} \times (\mathrm{Number\ of\ amplifiers}) \times 2{,}5\mathrm{mA} = 24 \times 3 \times 2{,}5\mathrm{E}-3 = 180\mathrm{mW} / \mathrm{Pixel}$$

Thus for one PM (4 pixels) :

$$\text{Total P} = 720 \text{ mW}$$

Simulation's results:

All simulations have been performed with the Cadence chain and AWBHDL 5.1 software. This software is compatible with the SPICE macromodel that we can find on semiconductor manufacturers' sites.

The first channel has been calculated using simulation. The values indicated for L1, C1, C2, R1, R2 make it possible to obtain a signal with a rise time roughly equal to 600ns for a peak voltage near to 9.6Volt.

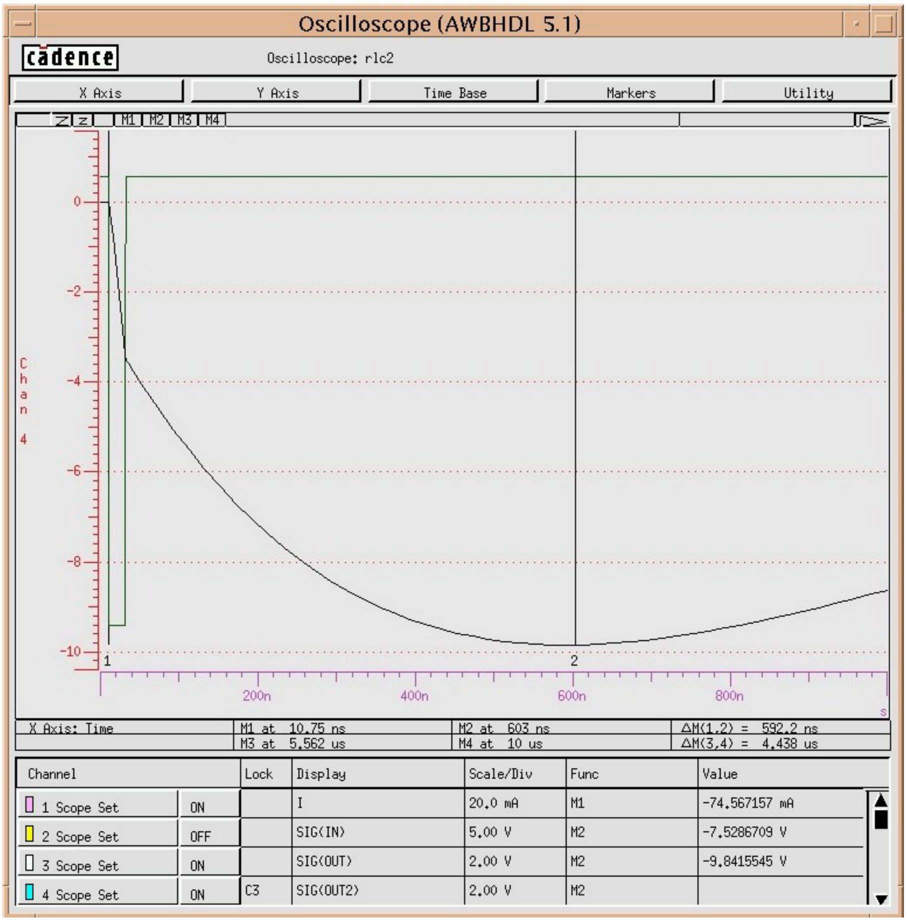


Figure 5 - Simulation of the RLC circuit (Voltage V1)

The $\dfrac{Delay}{Amplitude}$ compromise has been found for the following component values:

- C1 = 20pF
- L1 = 2.2mH
- R1 = 3.9KΩ
- R2 = 15KΩ
- C2 = 180pF

Notes:

- The resonance frequency of the inductance is 800 KHz.
- For simulation, the analog input signal is performed with a 20ns time width and a variable amplitude voltage, in order to seem to a photomultiplier signal as close as possible.

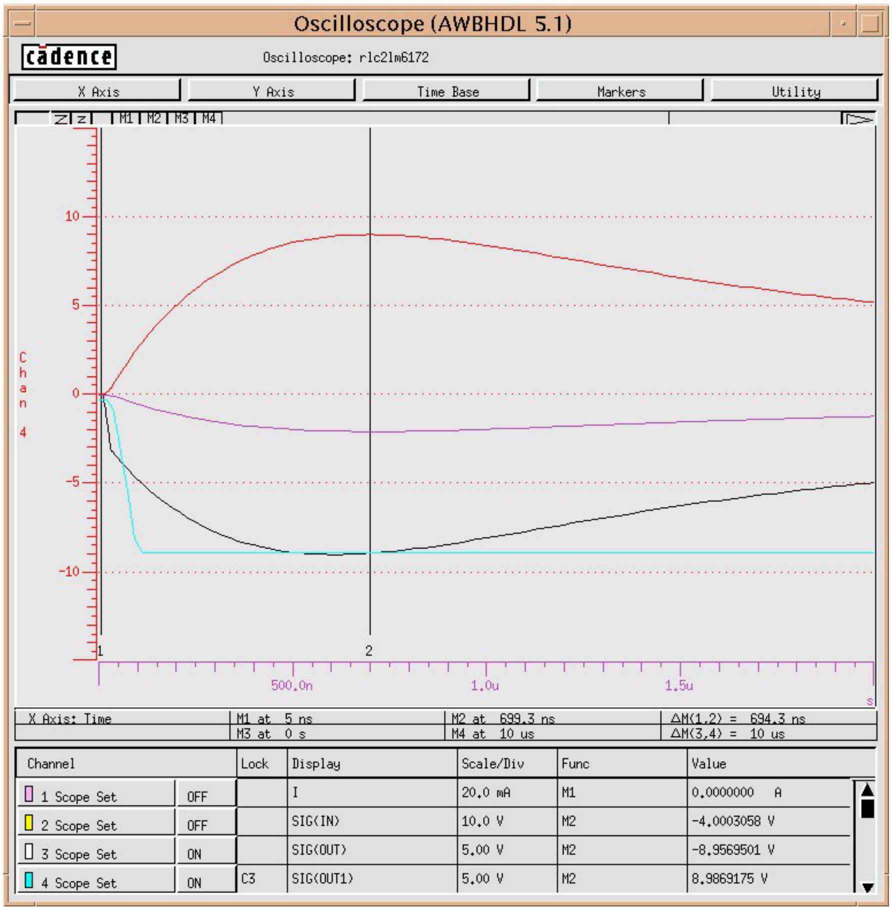


Figure 6 - Simulation of the entire circuit (VOUT_H, VOUT_L)

Explanations:

- Red curve is the output signal from the M1 amplifier (V2) connected like an inverter and thus positive.

- Blue curve is the saturated "high gain" channel (VOUT_H) and in purple one the "low gain" channel (VOUT_L) that is linear up to two Volts. A 50 Ω serial resistor was added to adapt the line and to input an identical value into the ADC. We create a divider by two because we load the ADC with a 50 Ω serial resistor.

- The values of the R4, R5, R6 resistors have been adjusted to obtain 5 for attenuation value between the two amplitude output voltages, and also to reach full-scale on the ADC (0 to -1 Volt). For measurement, signal offset will be added by injecting a continuous value of the same sign at the positive input of the M2, M3 amplifiers.

- M2 is a gain 4 inverter

- A delay is induced by two amplifier channels. This value has been verified in measurement, so peaking time is equal to 700ns.

Test bench:

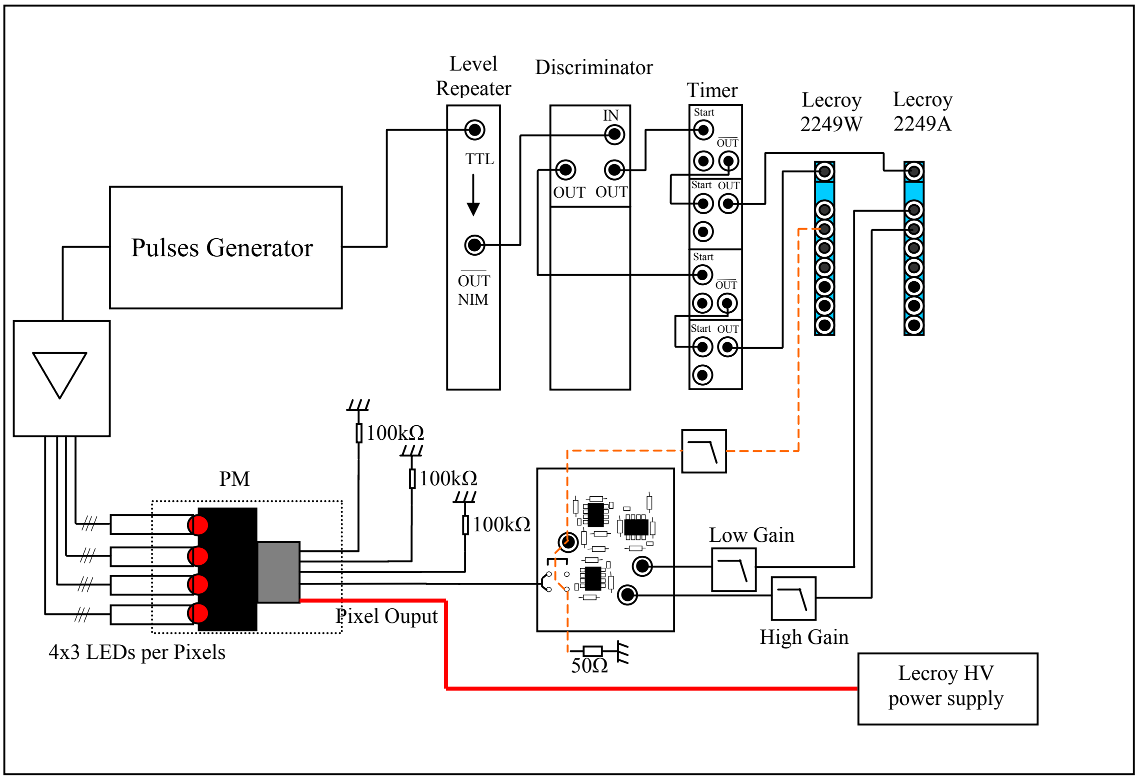


Figure 7 - Test Bench: Photomultiplier acquisition system with discrete circuit

The tests allowed us to evaluate the linearity of the circuit. They also allowed us to measure peaking time and noise and thus deduce system's dynamic.

Linearity:

To show that our system is linear, we produced the curve:
PM charge (pC) = function of ("High Gain value", "Low Gain value")

First we note the value charge value of the PM with a 50Ω load, and then for the same point we measure the amplitude of the "low gain" and "high gain" signals integrated in a narrow gate (approximately 100ns).

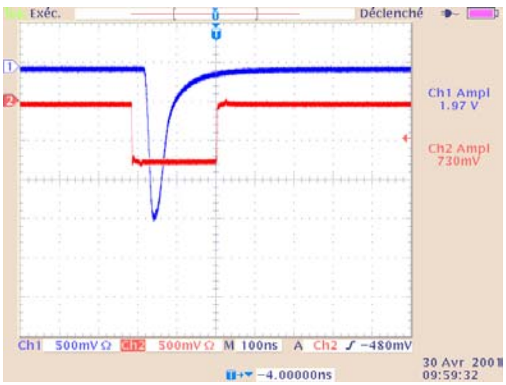


Figure 8 - PM signal charged at 50 Ohms

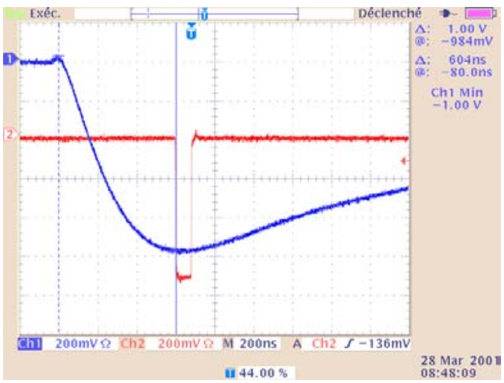


Figure 9 - PM signal charged on the discrete circuit

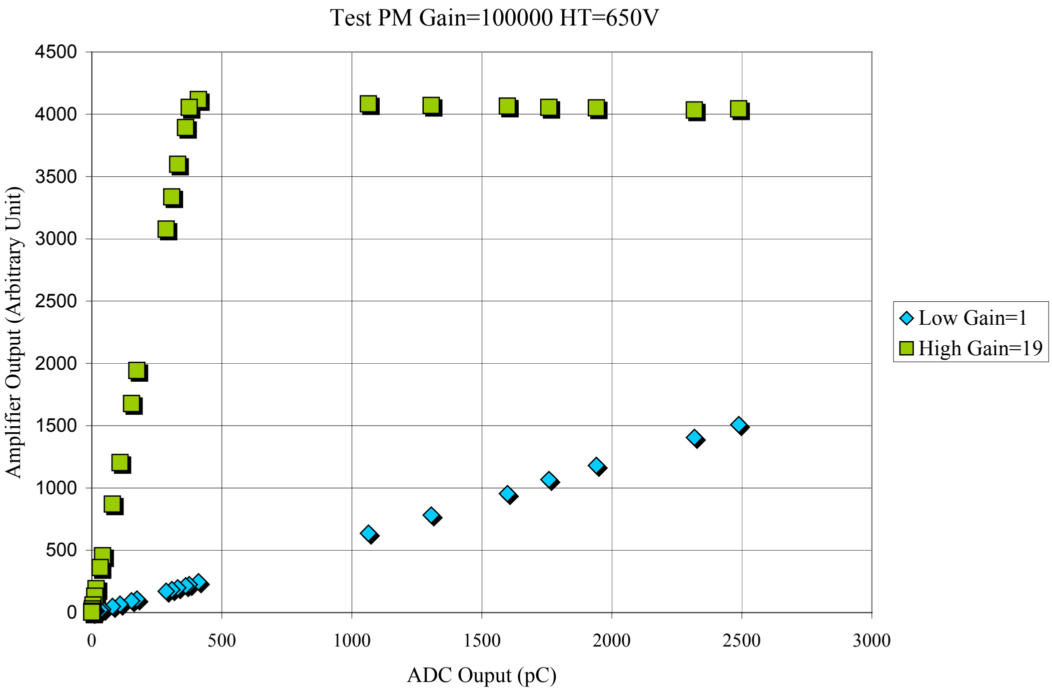


Figure 10 - Linearity strong signals

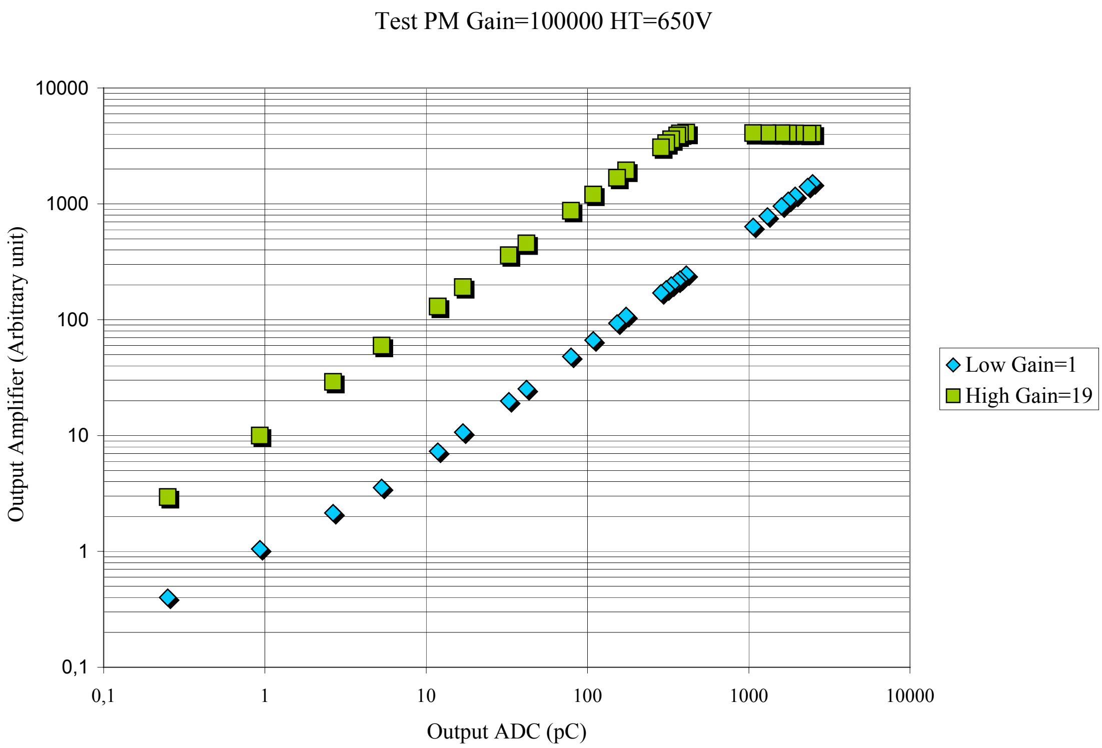


Figure 11 - Linearity weak signals

Linearity deviation:

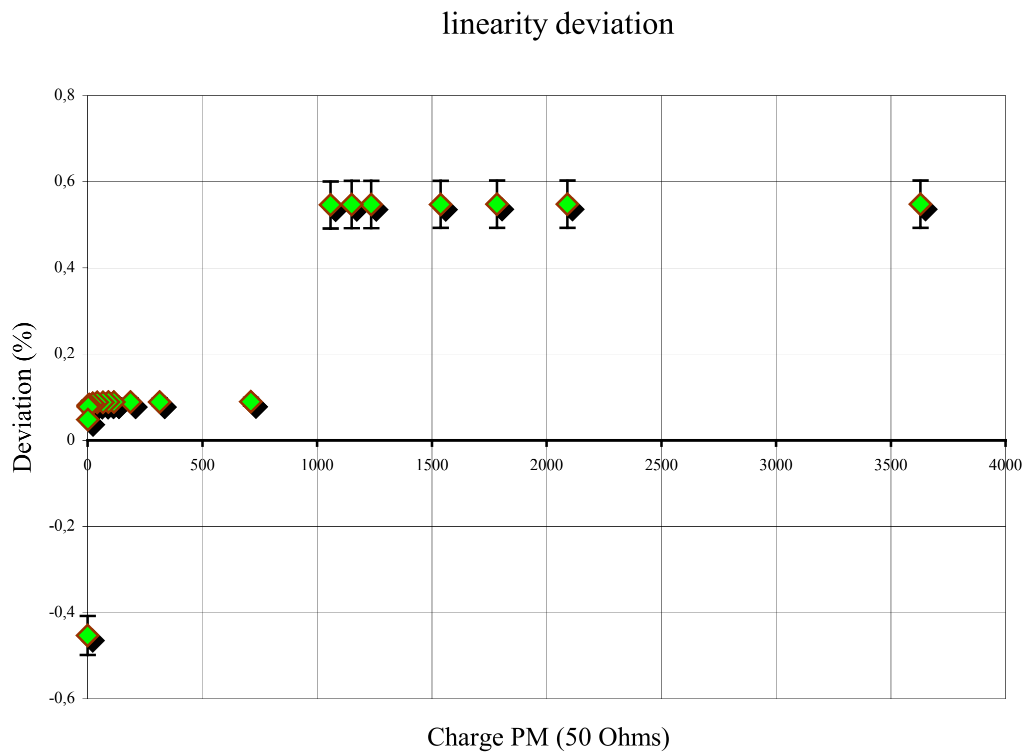


Figure 12 – Pulse linearity per chanel

Charge values are all in arbitrary units because values depend on the duration of the gate in which the signal is integrated. Gate duration does not affect results as long as it remains constant while data is collected. A unit value (0.25pC) and attenuation are associated with each pulse of the ADC.
For a measurement:

Charge = (Signal - Pedestal) x 0.25pC x Attenuation n

Linearity deviation corresponds to the specification because it does not exceed 0.5%. Its value is more exact for the High Gain output.

Signal responses:

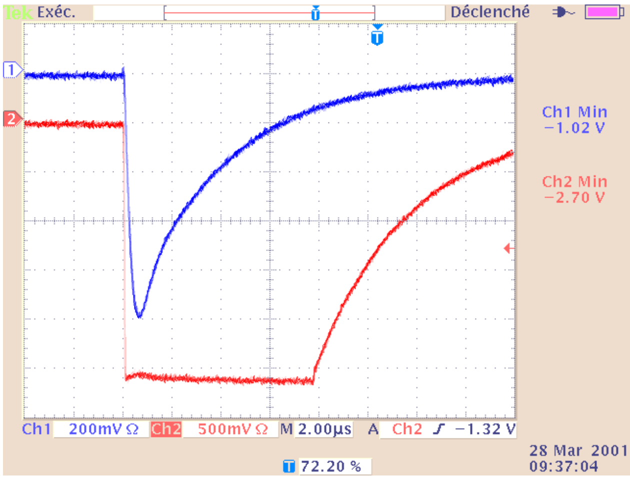


Figure 13 – Time response for low gain (2000pC)

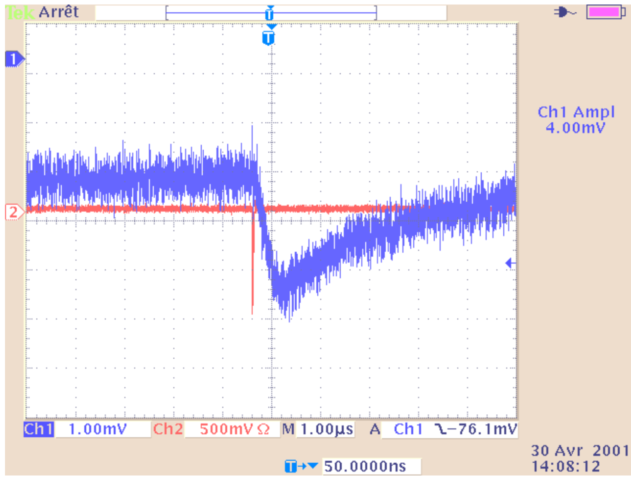


Figure 14 – Time response for high gain (0.25pC)

The figure above shows a signal for 2000pC calibrated at -1 Volt full scale.
For 0.25pC, the signal measured on the "High Gain" channel varies around an amplitude of -2mV plus -2mV of offset.
The figure below shows peaking times (2 Gains) in linear mode:

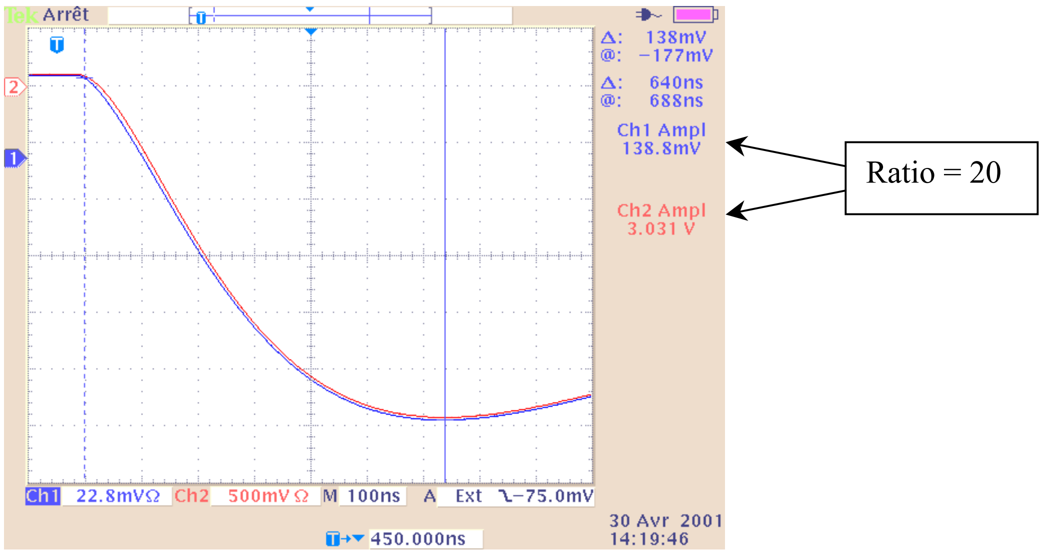
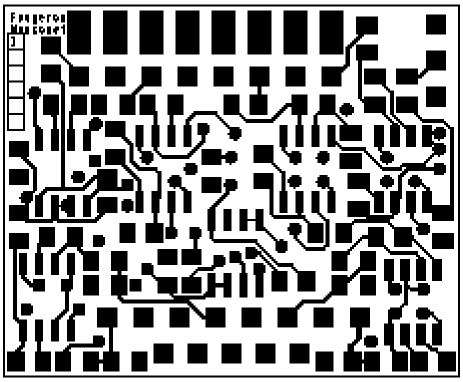


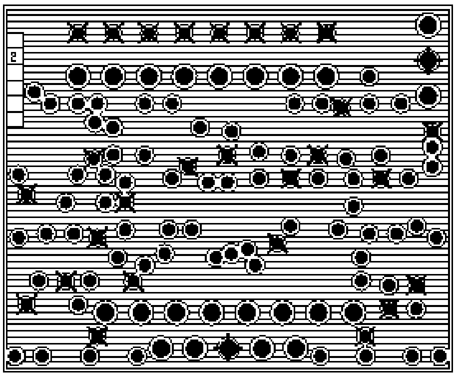
Figure 15 - Measurement of Peaking Time

Printed Board Circuit:

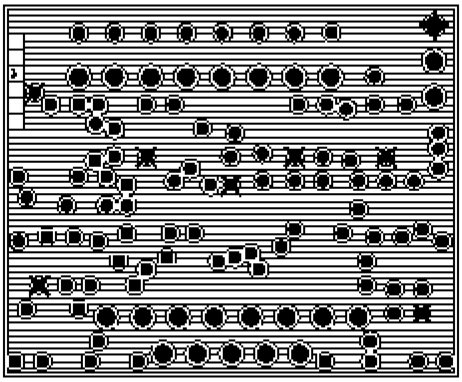
A board has been created in LAPP using the Cadence chain with Allegro version psd136 routing software. It is a 6-layers class 5 board (0.15 mm insulation). This board has been installed on the cosmic bench for testing.



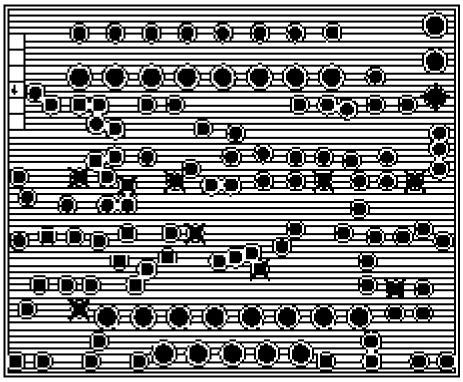
TOP



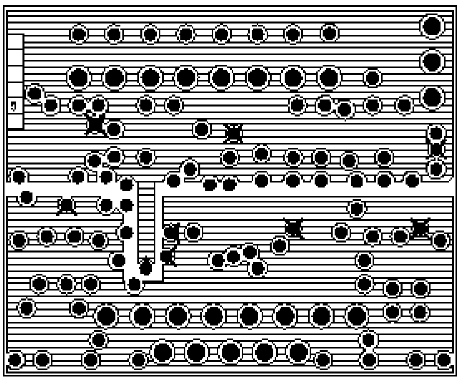
GND



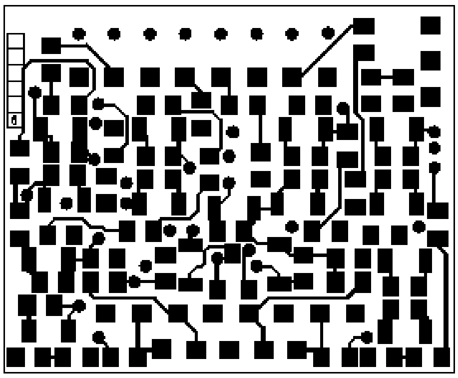
VDD



VSS



OFFset



BOTTOM

Noise:

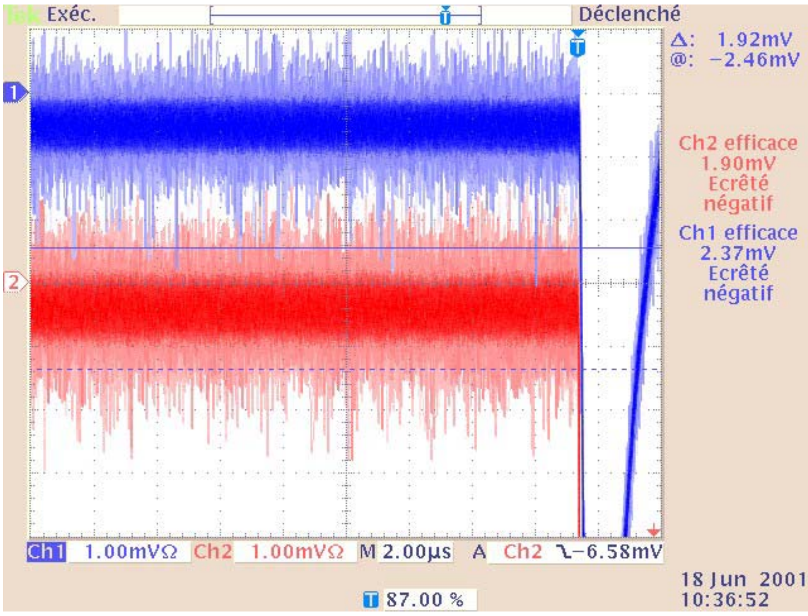


Figure 16 - Noise measurement

We encountered some problems in setting up the PM measurement chain + electronic system + ADC + data acquisition system.

1 - The CAMAC ADC is now outdated. Linearity measurements led us to wonder about the linearity of the ADC itself, particularly for small signals.

2 – When we have begun first measurements, a 50 Hz signal is injected by the laboratory power supplies we used onto the +/- 12V. To avoid this undesirable behavior, all the measurements, presented above, have been made using electric batteries. Noise associated with the electronics was thus greatly reduced.
Noise measured = 0.7 mV RMS

We decided to have a dynamic range of 10000 in the beginning and this objective has been achieved. Reducing noise allowed us to improve the dynamic range by a factor of three. With batteries we measured a dynamic range of D = 30000.

Conclusions:

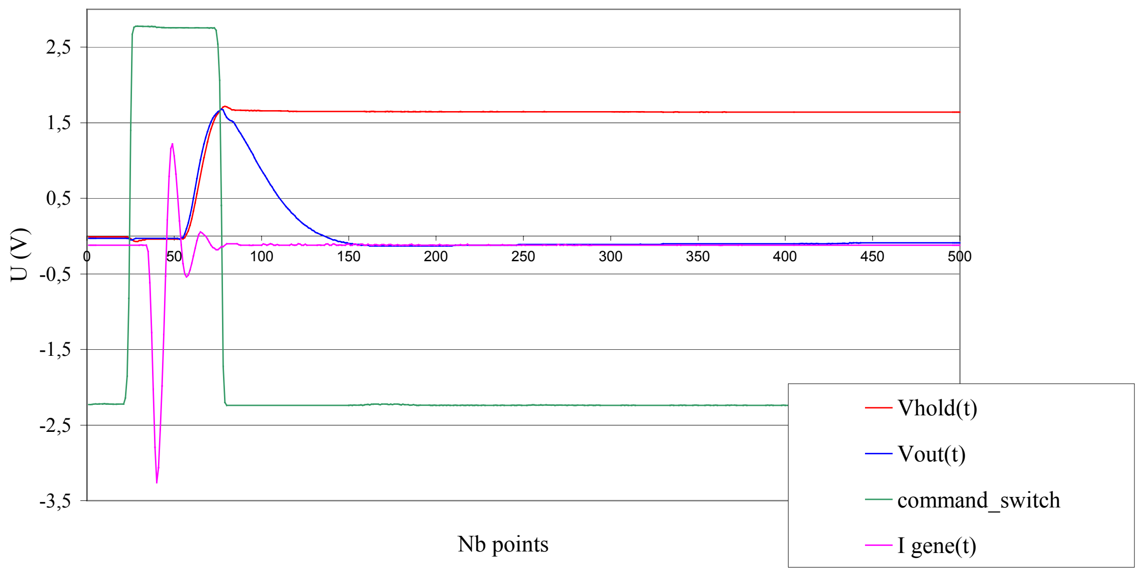
- This solution works well and measurements confirm the results of the simulation.

- We need electric batteries to improve system dynamics.

- Once we had determined all characteristics of our installation, we introduced a discrete front end board in the readout chain of the cosmic test bench. To synchronize with a particle signal, a coincidence is created with two scintillators, thereby introducing a delay of approximately 200 nanoseconds in triggering acquisition.
This delay is more shorter than our circuit's shaping time and this electronic system has been designed to feed into a Lecroy 2249 ADC with 50 Ω load. So this solution can be used in this experiment.

- This system could be used by calibrating signals to drive an AD7476 ADC (the ADC used in the AMS experiment) for which input impedance is more higher (Cin = 30pF).
This would optimize power consumption because we could choice an AOP with a current output more lower than LM6172 used.

- Initial tests have been made with an analog memory added before the ADC:



These tests are similar to the ASIC's architecture of the AMS02 calorimeter, in which the ADC ad7476 (analog devices) is a voltage ADC.
The analog information from the PM is in this case a continuous voltage that corresponds to the peak voltage value of the shaper.
Components added are digital components with little impact on power consumption.

Appendix 1

Acquisition Software(Pascal)

(* Acquisition loop *)

```
procedure TMonitorApp.StartAcquisition;
var
   Bounds:TRect;
   c:char;
   HistoScaler:PADCHisto;
   HistoFavier:PADCHisto;
   HistoRomanr:PADCHisto;
   HistoNeutrr:PADCHisto;
   HistoWindow:PHistoWindow;
   Event:TEvent;
   NN,NC,Q:byte;
   X,R1,R2,R3,R4,R5,R6:word;
   rr6:real;
   ic,ict:longint;
   ct:longint;
   rr1 : array[0..1000] of longint;
   rr2 : array[0..1000] of longint;
   rr3 : array[0..1000] of integer;
   rr4 : array[0..1200] of integer;
    ThisRun:longint;
   SaveFile:text;
   RunNumberFile:text;
   i,e:integer;
   HTitle,HTCh:String;
begin
    PilotWindow^.GetData(Module);
    PilotWindow^.Done;
    PilotWindow:=nil;
    with Module do begin
            Val(Run,ThisRun,e);
            if DoSave<>0  then begin
               ds:=true;
            end
            else ds:=false;
            RunNumber:=ThisRun;
    end;

    HistoScaler:=new(PADCHisto,Init('Ch1 '+Module.Title,0,0,0, (* Do not worry about these
numbers *)
             1026,-1.0,1024.0)); (* Histogram binning *)
    HistoFavier:=new(PADCHisto,Init('Ch2 '+Module.Title,0,0,0, (* Do not worry about these
numbers *)
             1026,-1.0,1024.0)); (* Histogram binning *)
    HistoRomanr:=new(PADCHisto,Init('Ch3 '+Module.Title,0,0,0, (* Do not worry about these
numbers *)
             1026,-1.0,1024.0)); (* Histogram binning *)
```

```
    HistoNeutrr:=new(PADCHisto,Init('Ch4 '+Module.Title,0,0,0, (* Do not worry about these
numbers *)
            1202,-1.0,1200.0)); (* Histogram binning *)
    HistoCol^.Insert(HistoScaler);      (* Put histo in window list *)
    HistoCol^.Insert(HistoFavier);      (* Put histo in window list *)
    HistoCol^.Insert(HistoRomanr);      (* Put histo in window list *)
    HistoCol^.Insert(HistoNeutrr);      (* Put histo in window list *)
    (* Recall histo list *)

    if ListWindow<>nil then begin
          ListWindow^.GetBounds(Bounds);
          ListWindow^.Done;
          ListWindow:=New(PListWindow,Init(HistoCol,Bounds,'View Histogram'));
          Insert(ListWindow);
    end
    else ViewHistograms;

   if ds then begin (* Open files *)
          assign(RunNumberFile,FILESPATH+RUNFILE);
          rewrite(RunNumberFile);
          writeln(RunNumberFile,RunNumber);
          close(RunNumberFile);
          assign(SaveFile,FILESPATH+Module.SaveFile);
          rewrite(SaveFile);
      Clock^.Update;
      writeln(SaveFile,'Start of ',Module.Title);
      writeln(SaveFile,Module.Comment);
      write(SaveFile,Clock^.Jour:2,'/',Clock^.Mois:2,'/',Clock^.Annee:4);
      writeln(SaveFile,' ',Clock^.heure:2,':',Clock^.minute:2,':',Clock^.Seconde:2);
      writeln(SaveFile);
    end;
          for i:=0 to 1000 do begin
      rr1[i]:=0;
      rr2[i]:=0;
      rr3[i]:=0;
      end;
          for i:=0 to 1200 do begin
      rr4[i]:=0;
      end;

          (* Acquisition loop *)
     DoAcquisition:=true;
     ct:=0;
     ic:=0;
     ict:=0;
     R1:=0;
     R2:=0;
     R3:=7;
     R4:=7;
     R5:=7;

     CAMAC(19,0,16,Q,X,R4);    (* Send computer is ready *)
      CAMAC(12,0,26,Q,X,R4); (* Enable LAM *)
     CAMAC(12,0,9,Q,X,R4); (* Clear module *)
```

```
 CAMAC(12,1,26,Q,X,R4); (* Enable LAM *)
CAMAC(12,1,9,Q,X,R4); (* Clear module *)
 CAMAC(14,0,26,Q,X,R4); (* Enable LAM *)
CAMAC(14,0,9,Q,X,R4); (* Clear module *)

 while DoAcquisition
do begin
  (* begin acquisition *)
   GetEvent(Event);      (*  Get mouse events *)
   HandleEvent(Event);    (*  Handle mouse events *)
(*        CAMAC(17,0,8,Q,X,R1);          (* enable ADC LAM in slot 17 *)
  CAMAC(12,0,8,Q,X,R4); (* Test LAM in slot 12 *)
   if Q>0 then begin (* LAM is enabled *)
  CAMAC(14,0,8,Q,X,R4); (* Test LAM in slot 14 *)
   if Q>0 then begin (* LAM is enabled *)
        (* CAMAC(SLOT,CHANNEL,FUNCTION,Q,X,R) *)
        R4:=4095;
     CAMAC(19,0,16,Q,X,R4);   (* Computer busy *)
       CAMAC(12,0,0,Q,X,R1);    (* Get ADC value *)
       CAMAC(12,1,0,Q,X,R2);    (* Get ADC value *)
     (*   CAMAC(12,0,0,Q,X,R4);    (* Get ADC value *)
       CAMAC(14,0,0,Q,X,R3);    (* Get TDC value *)
       CAMAC(14,1,0,Q,X,R5);    (* Get TDC value *)
      (*  CAMAC(14,1,0,Q,X,R6);    (* Get TDC value *)
              HistoScaler^.Fill(R1,1); (* Fill histo *)
              HistoFavier^.Fill(R2,1); (* Fill histo *)
              HistoRomanr^.Fill(R3,1); (* Fill histo *)
              HistoNeutrr^.Fill(R5,1); (* Fill histo *)
              if ds then begin
(*        if (r1>=36) or (r2>=36) then begin   *)
     (*
     write(SaveFile,ict:8,' ',R1:6,' ',R2:6,' ',R3:6,' ',R4:6);       (* write to file if save flag is on *)
   (*      writeln(SaveFile);
  (*       end;               *)
            if r1>=0 then begin
            if r1<=1000 then begin
            rr1[r1]:=rr1[r1]+1;
            end;
            end;
            if r2>=0 then begin
            if r2<=1000 then begin
            rr2[r2]:=rr2[r2]+1;
            end;
            end;
            if r3>=0 then begin
            if r3<=1000 then begin
            rr3[r3]:=rr3[r3]+1;
            end;
            end;
          (*   if r6>=0 then begin
            if r6<=1200 then begin
            rr4[r4]:=rr4[r4]+1;
            end;
            end;*)
```

```
            end;
           ic:=ic+1;
           ict:=ict+1;
 (*        Pour changer le taux de rafrechissement de l'ecran
          changer ic= ? dans la ligne suivante....   *)
           if ic=1000 then begin
             Draw;
             ic:=0;
           end;
(*              CAMAC(17,1,9,Q,X,R1);    *)
           CAMAC(12,1,9,Q,X,R4);
           R1:=7;
           CAMAC(12,2,9,Q,X,R4);
           R2:=7;
           CAMAC(14,1,9,Q,X,R4);
           R3:=7;
          (*  CAMAC(14,1,9,Q,X,R1);
           R4:=7;
           CAMAC(12,2,9,Q,X,R1);

           R4:=0;
           CAMAC(15,0,9,Q,X,R1);
           R6:=0;   *)
           CAMAC(19,0,16,Q,X,R4);    (* Send computer is ready *)
     end;
     end;
    end;             (* end of acquisition *)
    if ds then begin   (* Close files *)
      writeln(SaveFile,' ');
      for i:=0 to 1000 do begin
      writeln(SaveFile,i:9,rr1[i]:9,rr2[i]:9,rr3[i]:9,rr4[i]:9);
      end;
(*       for i:=1001 to 1200 do begin
      writeln(SaveFile,i:9,r6:9,r6:9,r6:9,rr4[i]:9);
      end;   *)
      Clock^.Update;
      writeln(SaveFile,'End of ',Module.Title);
      writeln(SaveFile,'Number of events stored : ',ict:9 );
      write(SaveFile,' ',Clock^.Jour:2,'/',Clock^.Mois:2,'/',Clock^.Annee:4);
      writeln(SaveFile,' ',Clock^.heure:2,':',Clock^.minute:2,':',Clock^.Seconde:2);
      writeln(SaveFile,' ');
      close(SaveFile);
    end;

end;
```

Appendix 2

Data sheet of LM6172
(National Semiconductor)

National Semiconductor

May 1999

LM6172
Dual High Speed, Low Power, Low Distortion, Voltage Feedback Amplifiers

General Description

The LM6172 is a dual high speed voltage feedback amplifier. It is unity-gain stable and provides excellent DC and AC performance. With 100 MHz unity-gain bandwidth, 3000V/μs slew rate and 50 mA of output current per channel, the LM6172 offers high performance in dual amplifiers; yet it only consumes 2.3 mA of supply current each channel.

The LM6172 operates on ±15V power supply for systems requiring large voltage swings, such as ADSL, scanners and ultrasound equipment. It is also specified at ±5V power supply for low voltage applications such as portable video systems.

The LM6172 is built with National's advanced VIP™ III (Vertically Integrated PNP) complementary bipolar process. See the LM6171 datasheet for a single amplifier with these same features.

Features

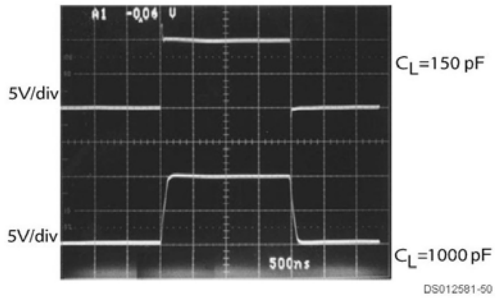
(Typical Unless Otherwise Noted)

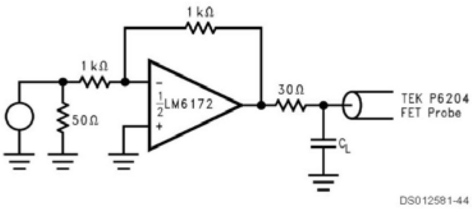
- Easy to Use Voltage Feedback Topology
- High Slew Rate 3000V/μs
- Wide Unity-Gain Bandwidth 100 MHz
- Low Supply Current 2.3 mA/Channel
- High Output Current 50 mA/channel
- Specified for ±15V and ±5V Operation

Applications

- Scanner I-to-V Converters
- ADSL/HDSL Drivers
- Multimedia Broadcast Systems
- Video Amplifiers
- NTSC, PAL® and SECAM Systems
- ADC/DAC Buffers
- Pulse Amplifiers and Peak Detectors

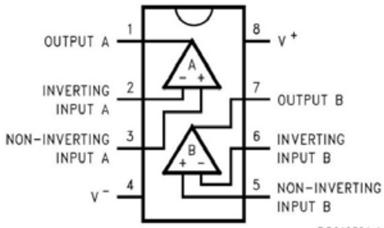
LM6172 Driving Capacitive Load





Connection Diagram

8-Pin DIP/SO



Top View

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Ordering Information

Package	Temperature Range		Transport Media	NSC Drawing
	Industrial −40˚C to +85˚C	Military −55˚C to +125˚C		
8-Pin DIP	LM6172IN		Rails	N08E
8-Pin CDIP	LM6172AMJ-QML	5962-95604	Rails	J08A
10-Pin Ceramic SOIC	LM6172AMWG-QML	5962-95604	Trays	WG10A
8-Pin Small Outline	LM6172IM		Rails	M08A
	LM6172IMX		Tape and Reel	

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

ESD Tolerance (Note 2)	
Human Body Model	3 kV
Machine Model	300V
Supply Voltage ($V^+ - V^-$)	36V
Differential Input Voltage (Note 9)	±10V
Output Short Circuit to Ground (Note 3)	Continuous
Storage Temp. Range	−65°C to +150°C
Maximum Junction Temperature (Note 4)	150°C

Operating Ratings (Note 1)

Supply Voltage	$5.5V \le V_S \le 36V$
Junction Temperature Range	
LM6172I	$-40°C \le T_J \le +85°C$
Thermal Resistance (θ_{JA})	
N Package, 8-Pin Molded DIP	95°C/W
M Package, 8-Pin Surface Mount	160°C/W

±15V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25°C,V^+ = +15V, V^- = −15V, V_{CM} = 0V, and R_L = 1 kΩ. **Boldface** limits apply at the temperature extremes

Symbol	Parameter	Conditions	Typ (Note 5)	LM6172I Limit (Note 5)	Units
V_{OS}	Input Offset Voltage		0.4	3	mV
				4	max
TC V_{OS}	Input Offset Voltage Average Drift		6		μV/°C
I_B	Input Bias Current		1.2	3	μA
				4	max
I_{OS}	Input Offset Current		0.02	2	μA
				3	max
R_{IN}	Input Resistance	Common Mode	40		MΩ
		Differential Mode	4.9		
R_O	Open Loop Output Resistance		14		Ω
CMRR	Common Mode Rejection Ratio	V_{CM} = ±10V	110	70	dB
				65	min
PSRR	Power Supply Rejection Ratio	V_S = ±15V to ±5V	95	75	dB
				70	min
A_V	Large Signal Voltage Gain (Note 6)	R_L = 1 kΩ	86	80	dB
				75	min
		R_L = 100Ω	78	65	dB
				60	min
V_O	Output Swing	R_L = 1 kΩ	13.2	12.5	V
				12	min
			−13.1	−12.5	V
				−12	max
		R_L = 100Ω	9	6	V
				5	min
			−8.5	−6	V
				−5	max
	Continuous Output Current (Open Loop) (Note 7)	Sourcing, R_L = 100Ω	90	60	mA
				50	min
		Sinking, R_L = 100Ω	−85	−60	mA
				−50	max
I_{SC}	Output Short Circuit Current	Sourcing	107		mA
		Sinking	−105		mA
I_S	Supply Current	Both Amplifiers	4.6	8	mA

±15V DC Electrical Characteristics (Continued)

Unless otherwise specified, all limits guaranteed for T_J = 25˚C,V^+ = +15V, V^- = −15V, V_{CM} = 0V, and R_L = 1 kΩ. **Boldface** limits apply at the temperature extremes

Symbol	Parameter	Conditions	Typ (Note 5)	LM6172I Limit (Note 5)	Units
				9	max

±15V AC Electrical Characteristics

Unless otherwise specified, T_J = 25˚C, V^+ = +15V, V^- = −15V, V_{CM} = 0V, and R_L = 1 kΩ

Symbol	Parameter	Conditions	LM6172I Typ (Note 5)	Units
SR	Slew Rate	A_V = +2, V_{IN} = 13 V_{PP}	3000	V/μs
		A_V = +2, V_{IN} = 10 V_{PP}	2500	V/μs
	Unity-Gain Bandwidth		100	MHz
	−3 dB Frequency	A_V = +1	160	MHz
		A_V = +2	62	MHz
	Bandwidth Matching between Channels		2	MHz
ϕ_m	Phase Margin		40	Deg
t_s	Settling Time (0.1%)	A_V = −1, V_{OUT} = ±5V, R_L = 500Ω	65	ns
A_D	Differential Gain (Note 8)		0.28	%
ϕ_D	Differential Phase (Note 8)		0.6	Deg
e_n	Input-Referred Voltage Noise	f = 1 kHz	12	$\frac{pA}{\sqrt{Hz}}$
i_n	Input-Referred Current Noise	f = 1 kHz	1	$\frac{nV}{\sqrt{Hz}}$
	Second Harmonic Distortion (Note 10)	f = 10 kHz	−110	dB
		f = 5 MHz	−50	dB
	Third Harmonic Distortion (Note 10)	f = 10 kHz	−105	dB
		f = 5 MHz	−50	dB

±5V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for T_J = 25˚C, V^+ = +5V, V^- = −5V, V_{CM} = 0V, and R_L = 1 kΩ. **Boldface** limits apply at the temperature extremes

Symbol	Parameter	Conditions	Typ (Note 5)	LM6172I Limit (Note 5)	Units
V_{OS}	Input Offset Voltage		0.1	3 **4**	mV max
TC V_{OS}	Input Offset Voltage Average Drift		4		μV/˚C
I_B	Input Bias Current		1.4	2.5 **3.5**	μA max
I_{OS}	Input Offset Current		0.02	1.5 **2.2**	μA max
R_{IN}	Input Resistance	Common Mode	40		MΩ
		Differential Mode	4.9		
R_O	Output Resistance		14		Ω
CMRR	Common Mode Rejection Ratio	V_{CM} = ±2.5V	105	70	dB

±5V DC Electrical Characteristics (Continued)

Unless otherwise specified, all limits guaranteed for T_J = 25°C, V^+ = +5V, V^- = −5V, V_{CM} = 0V, and R_L = 1 kΩ. **Boldface** limits apply at the temperature extremes

Symbol	Parameter	Conditions	Typ (Note 5)	LM6172I Limit (Note 5)	Units
				65	min
PSRR	Power Supply Rejection Ratio	V_S = ±15V to ±5V	95	75	dB
				70	min
A_V	Large Signal Voltage Gain (Note 6)	R_L = 1 kΩ	82	70	dB
				65	min
		R_L = 100Ω	78	65	dB
				60	min
V_O	Output Swing	R_L = 1 kΩ	3.4	3.1	V
				3	min
			−3.3	−3.1	V
				−3	max
		R_L = 100Ω	2.9	2.5	V
				2.4	min
			−2.7	−2.4	V
				−2.3	max
	Continuous Output Current (Open Loop) (Note 7)	Sourcing, R_L = 100Ω	29	25	mA
				24	min
		Sinking, R_L = 100Ω	−27	−24	mA
				−23	max
I_{SC}	Output Short Circuit Current	Sourcing	93		mA
		Sinking	−72		mA
I_S	Supply Current	Both Amplifiers	4.4	6	mA
				7	max

±5V AC Electrical Characteristics

Unless otherwise specified, T_J = 25°C, V^+ = +5V, V^- = −5V, V_{CM} = 0V, and R_L = 1 kΩ.

Symbol	Parameter	Conditions	LM61722 Typ (Note 5)	Units
SR	Slew Rate	A_V = +2, V_{IN} = 3.5 V_{PP}	750	V/μs
	Unity-Gain Bandwidth		70	MHz
	−3 dB Frequency	A_V = +1	130	MHz
		A_V = +2	45	MHz
ϕ_m	Phase Margin		57	Deg
t_s	Settling Time (0.1%)	A_V = −1, V_{OUT} = ±1V, R_L = 500Ω	72	ns
A_D	Differential Gain (Note 8)		0.4	%
ϕ_D	Differential Phase (Note 8)		0.7	Deg
e_n	Input-Referred Voltage Noise	f = 1 kHz	11	$\frac{nV}{\sqrt{Hz}}$
i_n	Input-Referred Current Noise	f = 1 kHz	1	$\frac{pA}{\sqrt{Hz}}$
	Second Harmonic Distortion (Note 10)	f = 10 kHz	−110	dB
		f = 5 MHz	−48	dB
	Third Harmonic	f = 10 kHz	−105	dB

±5V AC Electrical Characteristics (Continued)

Unless otherwise specified, T_J = 25˚C, V^+ = +5V, V^- = −5V, V_{CM} = 0V, and R_L = 1 kΩ.

Symbol	Parameter	Conditions	LM61722 Typ (Note 5)	Units
	Distortion (Note 10)	f = 5 MHz	−50	dB

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and the test conditions, see the Electrical Characteristics.

Note 2: Human body model, 1.5 kΩ in series with 100 pF. Machine Model, 200Ω in series with 100 pF.

Note 3: Continuous short circuit operation can result in exceeding the maximum allowed junction temperature of 150˚C.

Note 4: The maximum power dissipation is a function of $T_{J(max)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{J(max)} - T_A)/\theta_{JA}$. All numbers apply for packages soldered directly into a PC board.

Note 5: Typical Values represent the most likely parametric norm.

Note 6: All limits are guaranteed by testing or statistical analysis.

Note 7: Large signal voltage gain is the total output swing divided by the input signal required to produce that swing. For V_S = ±15V, V_{OUT} = ±5V. For V_S = ±5V, V_{OUT} = ±1V.

Note 8: The open loop output current is the output swing with the 100Ω load resistor divided by that resistor.

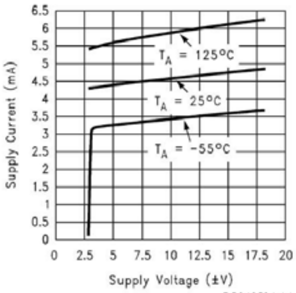
Note 9: Differential gain and phase are measured with A_V = +2, V_{IN} = 1 V_{PP} at 3.58 MHz and both input and output 75Ω terminated.

Note 10: Differential input voltage is applied at V_S = ±15V.

Note 11: Harmonics are measured with A_V = +2, V_{IN} = 1 V_{PP} and R_L = 100Ω.

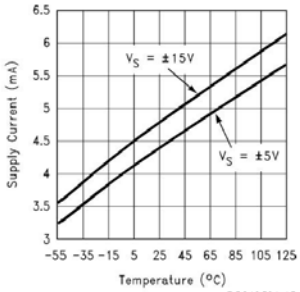
Typical Performance Characteristics unless otherwise noted, T_A = 25˚C

Supply Voltage vs Supply Current



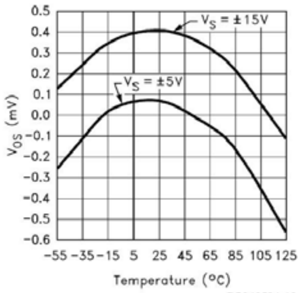
DS012581-14

Supply Current vs Temperature



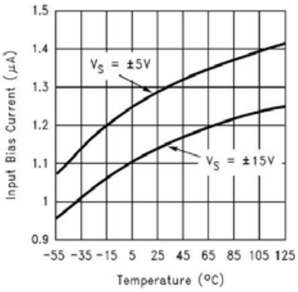
DS012581-15

Input Offset Voltage vs Temperature



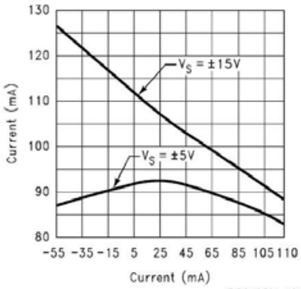
DS012581-16

Input Bias Current vs Temperature



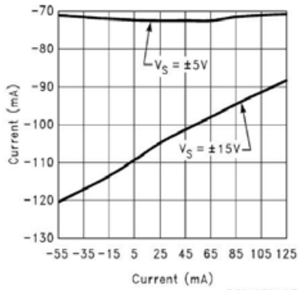
DS012581-17

Short Circuit Current vs Temperature (Sourcing)



DS012581-18

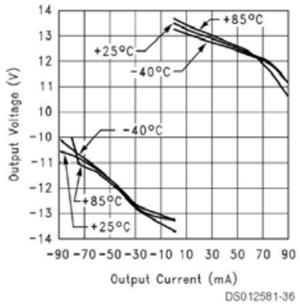
Short Circuit Current vs Temperature (Sinking)



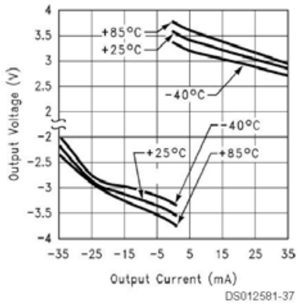
DS012581-35

Typical Performance Characteristics unless otherwise noted, T_A = 25˚C (Continued)

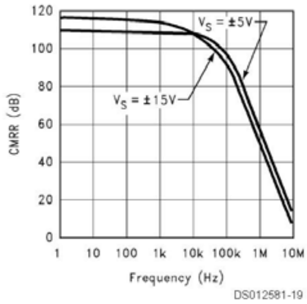
Output Voltage vs Output Current (V_S = ±15V)



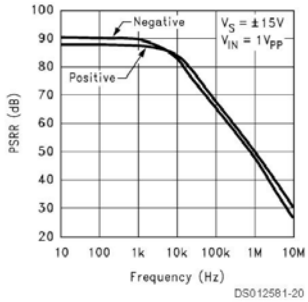
Output Voltage vs Output Current (V_S = ±5V)



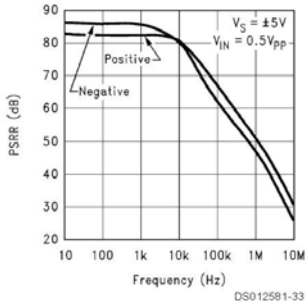
CMRR vs Frequency



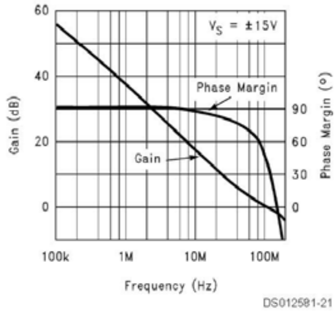
PSRR vs Frequency



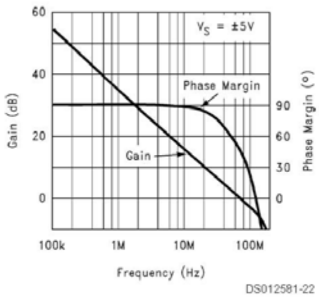
PSRR vs Frequency



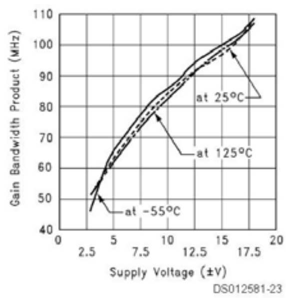
Open-Loop Frequency Response



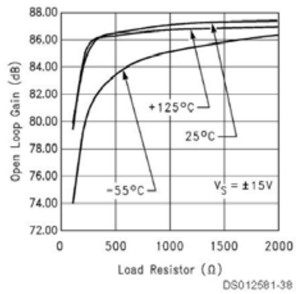
Open-Loop Frequency Response



Gain-Bandwidth Product vs Supply Voltage at Different Temperature

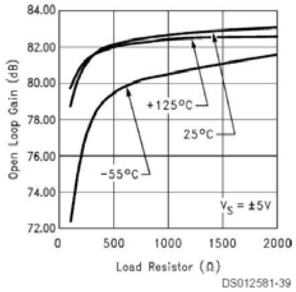


Large Signal Voltage Gain vs Load

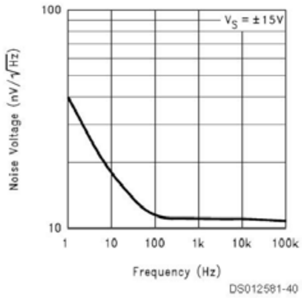


Typical Performance Characteristics unless otherwise noted, T_A = 25˚C (Continued)

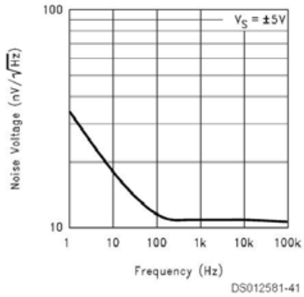
Large Signal Voltage Gain vs Load



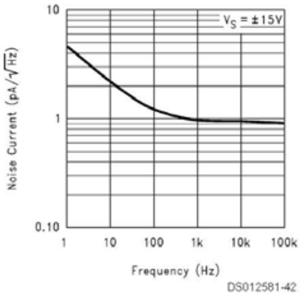
Input Voltage Noise vs Frequency



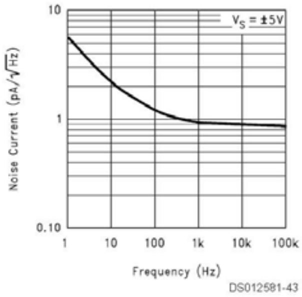
Input Voltage Noise vs Frequency



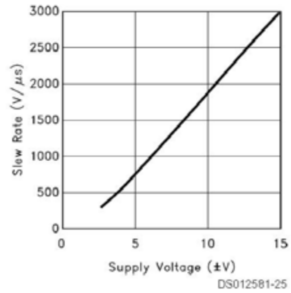
Input Current Noise vs Frequency



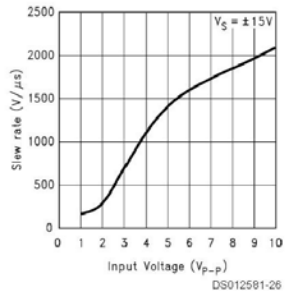
Input Current Noise vs Frequency



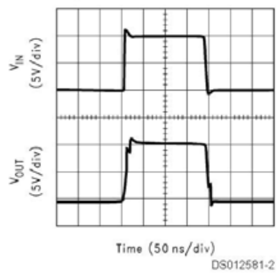
Slew Rate vs Supply Voltage



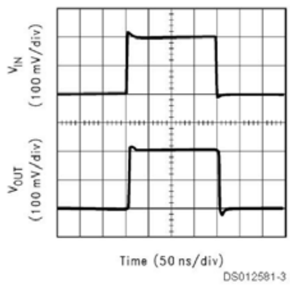
Slew Rate vs Input Voltage



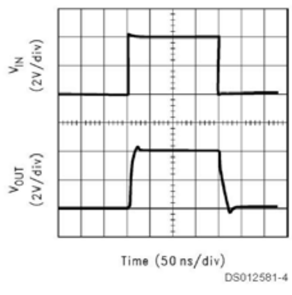
Large Signal Pulse Response A_V = +1, V_S = ±15V



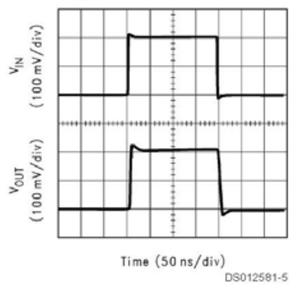
Small Signal Pulse Response A_V = +1, V_S = ±15V



Large Signal Pulse Response A_V = +1, V_S = ±5V

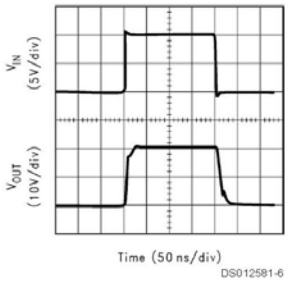


Small Signal Pulse Response A_V = +1, V_S = ±5V

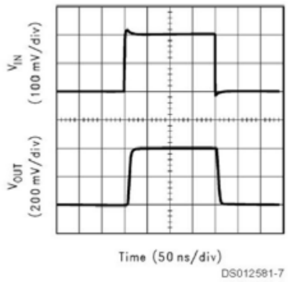


Typical Performance Characteristics unless otherwise noted, T_A = 25°C (Continued)

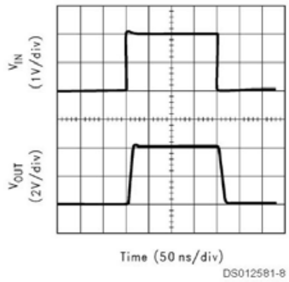
Large Signal Pulse Response
A_V = +2, V_S = ±15V



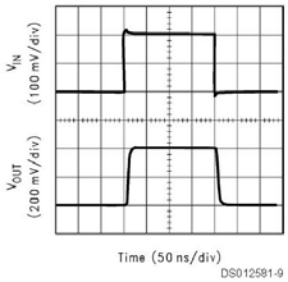
Small Signal Pulse Response
A_V = +2, V_S = ±15V



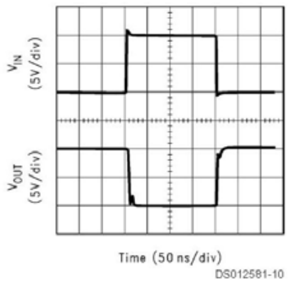
Large Signal Pulse Response
A_V = +2, V_S = ±5V



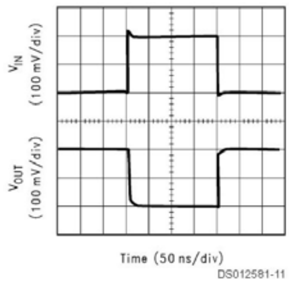
Small Signal Pulse Response
A_V = +2, V_S = ±5V



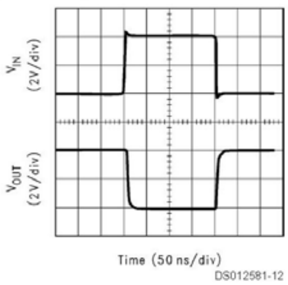
Large Signal Pulse Response
A_V = −1, V_S = ±15V



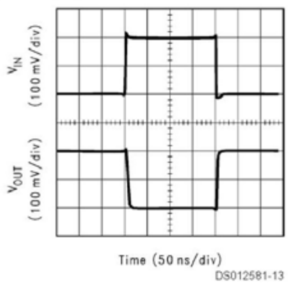
Small Signal Pulse Response
A_V = −1, V_S = ±15V



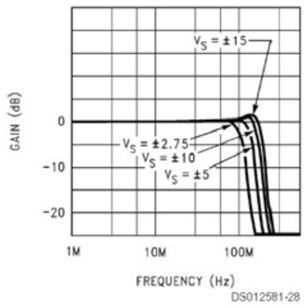
Large Signal Pulse Response
A_V = −1, V_S = ±5V



Small Signal Pulse Response
A_V = −1, V_S = ±5V

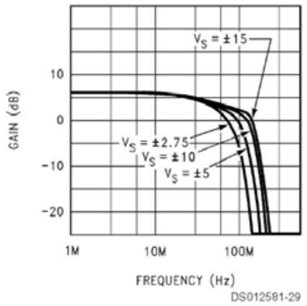


Closed Loop Frequency Response vs Supply Voltage (A_V = +1)

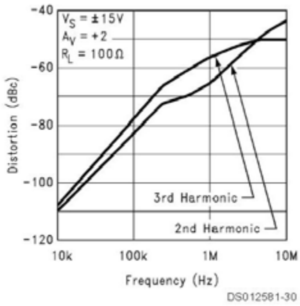


Typical Performance Characteristics unless otherwise noted, T_A = 25˚C (Continued)

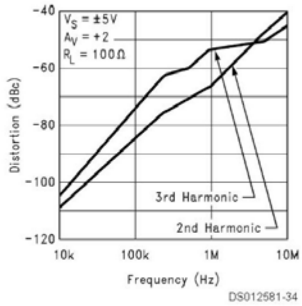
Closed Loop Frequency Response vs Supply Voltage (A_V = +2)



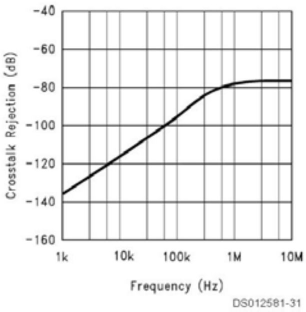
Harmonic Distortion vs Frequency (V_S = ±15V)



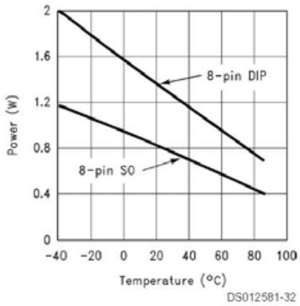
Harmonic Distortion vs Frequency (V_S = ±5V)



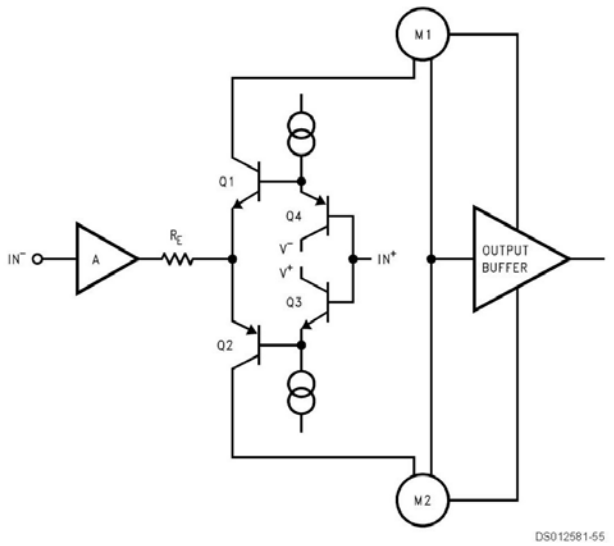
Crosstalk Rejection vs Frequency



Maximum Power Dissipation vs Ambient Temperature



½ LM6172 Simplified Schematic



Application Notes

LM6172 Performance Discussion

The LM6172 is a dual high-speed, low power, voltage feedback amplifier. It is unity-gain stable and offers outstanding performance with only 2.3 mA of supply current per channel. The combination of 100 MHz unity-gain bandwidth, 3000V/µs slew rate, 50 mA per channel output current and other attractive features makes it easy to implement the LM6172 in various applications. Quiescent power of the LM6172 is 138 mW operating at ±15V supply and 46 mW at ±5V supply.

LM6172 Circuit Operation

The class AB input stage in LM6172 is fully symmetrical and has a similar slewing characteristic to the current feedback amplifiers. In the LM6172 Simplified Schematic, Q1 through Q4 form the equivalent of the current feedback input buffer, R_E the equivalent of the feedback resistor, and stage A buffers the inverting input. The triple-buffered output stage isolates the gain stage from the load to provide low output impedance.

LM6172 Slew Rate Characteristic

The slew rate of LM6172 is determined by the current available to charge and discharge an internal high impedance node capacitor. This current is the differential input voltage divided by the total degeneration resistor R_E. Therefore, the slew rate is proportional to the input voltage level, and the higher slew rates are achievable in the lower gain configurations.

When a very fast large signal pulse is applied to the input of an amplifier, some overshoot or undershoot occurs. By placing an external series resistor such as 1 kΩ to the input of LM6172, the slew rate is reduced to help lower the overshoot, which reduces settling time.

Reducing Settling Time

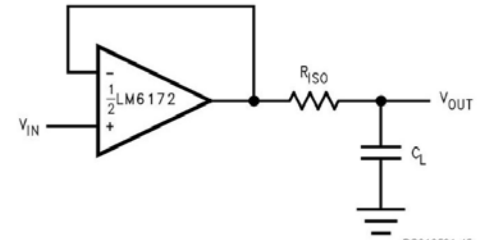
The LM6172 has a very fast slew rate that causes overshoot and undershoot. To reduce settling time on LM6172, a 1 kΩ resistor can be placed in series with the input signal to decrease slew rate. A feedback capacitor can also be used to reduce overshoot and undershoot. This feedback capacitor serves as a zero to increase the stability of the amplifier circuit. A 2 pF feedback capacitor is recommended for initial evaluation. When the LM6172 is configured as a buffer, a feedback resistor of 1 kΩ must be added in parallel to the feedback capacitor.

Another possible source of overshoot and undershoot comes from capacitive load at the output. Please see the section “Driving Capacitive Loads” for more detail.

Driving Capacitive Loads

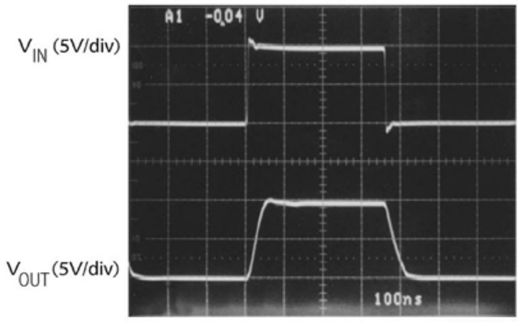
Amplifiers driving capacitive loads can oscillate or have ringing at the output. To eliminate oscillation or reduce ringing, an isolation resistor can be placed as shown in *Figure 1.* The combination of the isolation resistor and the load capacitor forms a pole to increase stability by adding more phase margin to the overall system. The desired performance depends on the value of the isolation resistor; the bigger the isolation resistor, the more damped (slow) the pulse response becomes. For LM6172, a 50Ω isolation resistor is recommended for initial evaluation.

Driving Capacitive Loads (Continued)



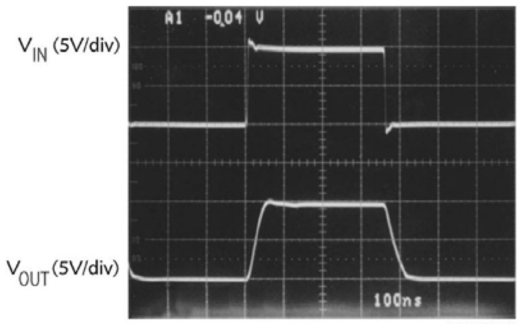
DS012581-45

FIGURE 1. Isolation Resistor Used to Drive Capacitive Load



DS012581-51

FIGURE 2. The LM6172 Driving a 510 pF Load with a 30Ω Isolation Resistor



DS012581-52

FIGURE 3. The LM6172 Driving a 220 pF Load with a 50Ω Isolation Resistor

Layout Consideration

PRINTED CIRCUIT BOARDS AND HIGH SPEED OP AMPS

There are many things to consider when designing PC boards for high speed op amps. Without proper caution, it is very easy to have excessive ringing, oscillation and other degraded AC performance in high speed circuits. As a rule, the signal traces should be short and wide to provide low inductance and low impedance paths. Any unused board space needs to be grounded to reduce stray signal pickup. Critical components should also be grounded at a common point to eliminate voltage drop. Sockets add capacitance to the board and can affect frequency performance. It is better to solder the amplifier directly into the PC board without using any socket.

USING PROBES

Active (FET) probes are ideal for taking high frequency measurements because they have wide bandwidth, high input impedance and low input capacitance. However, the probe ground leads provide a long ground loop that will produce errors in measurement. Instead, the probes can be grounded directly by removing the ground leads and probe jackets and using scope probe jacks.

COMPONENTS SELECTION AND FEEDBACK RESISTOR

It is important in high speed applications to keep all component leads short because wires are inductive at high frequency. For discrete components, choose carbon composition-type resistors and mica-type capacitors. Surface mount components are preferred over discrete components for minimum inductive effect.

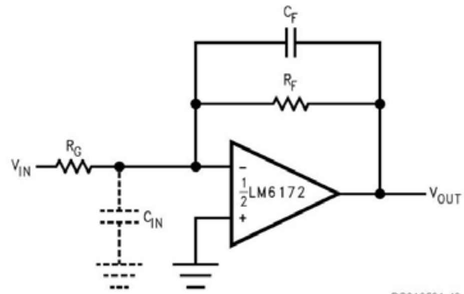
Large values of feedback resistors can couple with parasitic capacitance and cause undesirable effects such as ringing or oscillation in high speed amplifiers. For LM6172, a feedback resistor less than 1 kΩ gives optimal performance.

Compensation for Input Capacitance

The combination of an amplifier's input capacitance with the gain setting resistors adds a pole that can cause peaking or oscillation. To solve this problem, a feedback capacitor with a value

$$C_F > (R_G \times C_{IN})/R_F$$

can be used to cancel that pole. For LM6172, a feedback capacitor of 2 pF is recommended. *Figure 4* illustrates the compensation circuit.



DS012581-46

FIGURE 4. Compensating for Input Capacitance

Power Supply Bypassing

Bypassing the power supply is necessary to maintain low power supply impedance across frequency. Both positive and negative power supplies should be bypassed individually by placing 0.01 µF ceramic capacitors directly to power supply pins and 2.2 µF tantalum capacitors close to the power supply pins.

Power Supply Bypassing (Continued)

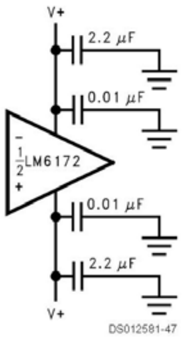


FIGURE 5. Power Supply Bypassing

Termination

In high frequency applications, reflections occur if signals are not properly terminated. *Figure 6* shows a properly terminated signal while *Figure 7* shows an improperly terminated signal.

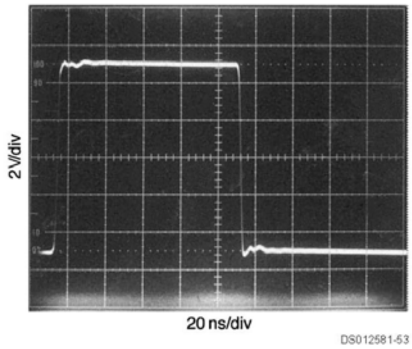


FIGURE 6. Properly Terminated Signal

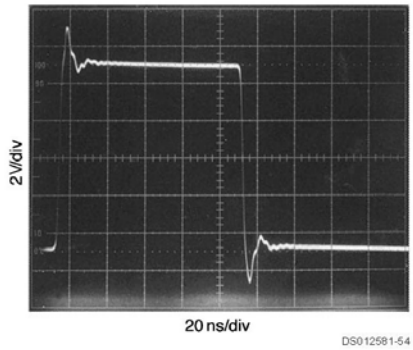


FIGURE 7. Improperly Terminated Signal

To minimize reflection, coaxial cable with matching characteristic impedance to the signal source should be used. The other end of the cable should be terminated with the same value terminator or resistor. For the commonly used cables, RG59 has 75Ω characteristic impedance, and RG58 has 50Ω characteristic impedance.

Power Dissipation

The maximum power allowed to dissipate in a device is defined as:

$$P_D = (T_{J(max)} - T_A)/\theta_{JA}$$

Where P_D is the power dissipation in a device

$T_{J(max)}$ is the maximum junction temperature

T_A is the ambient temperature

θ_{JA} is the thermal resistance of a particular package

For example, for the LM6172 in a SO-8 package, the maximum power dissipation at 25˚C ambient temperature is 780 mW.

Thermal resistance, θ_{JA}, depends on parameters such as die size, package size and package material. The smaller the die size and package, the higher θ_{JA} becomes. The 8-pin DIP package has a lower thermal resistance (95˚C/W) than that of 8-pin SO (160˚C/W). Therefore, for higher dissipation capability, use an 8-pin DIP package.

The total power dissipated in a device can be calculated as:

$$P_D = P_Q + P_L$$

P_Q is the quiescent power dissipated in a device with no load connected at the output. P_L is the power dissipated in the device with a load connected at the output; it is not the power dissipated by the load.

Furthermore,

P_Q: = supply current x total supply voltage with no load

P_L: = output current x (voltage difference between supply voltage and output voltage of the same supply)

For example, the total power dissipated by the LM6172 with V_S = ±15V and both channels swinging output voltage of 10V into 1 kΩ is

P_D: = $P_Q + P_L$

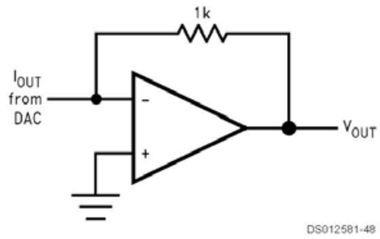
: = 2[(2.3 mA)(30V)] + 2[(10 mA)(15V − 10V)]

: = 138 mW + 100 mW

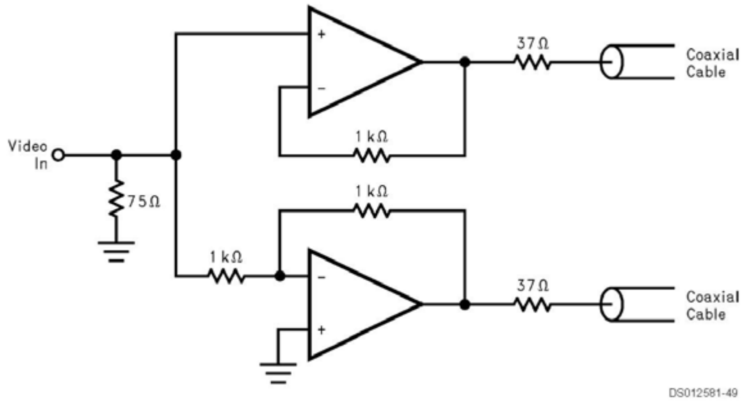
: = 238 mW

Application Circuits

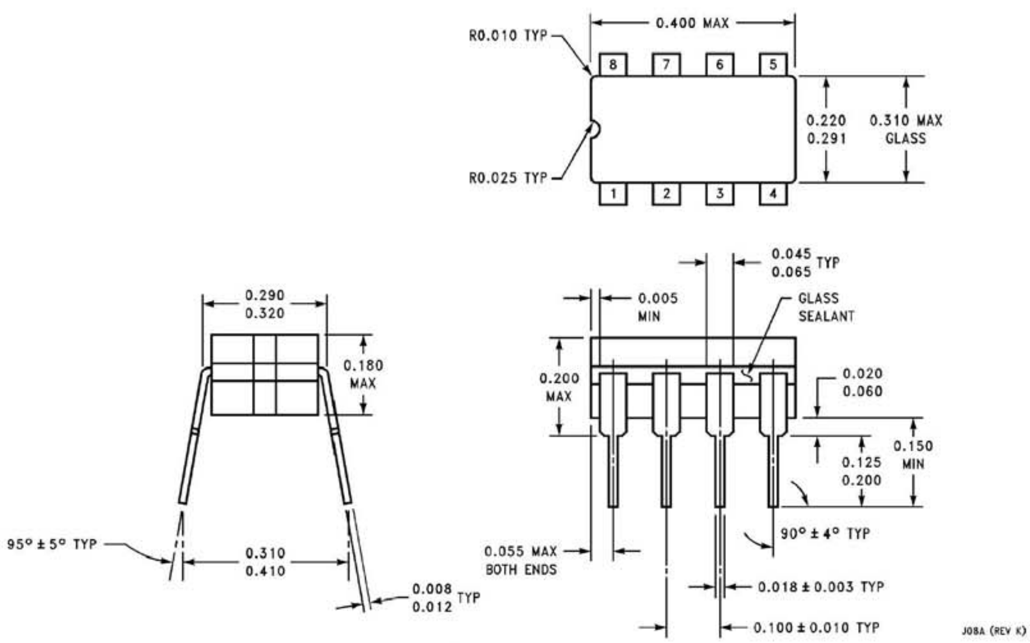
I-to-V Converters



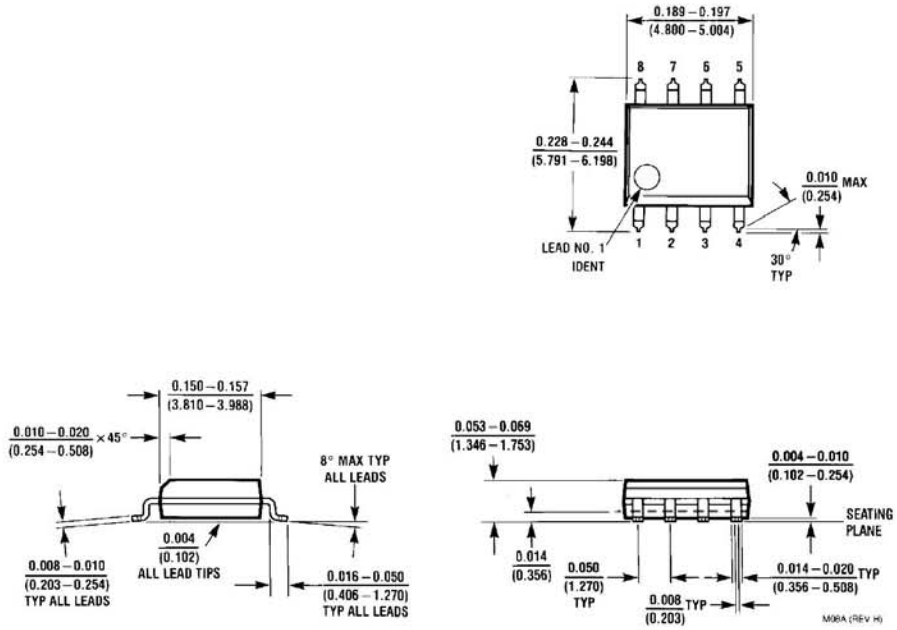
Differential Line Driver



Physical Dimensions inches (millimeters) unless otherwise noted

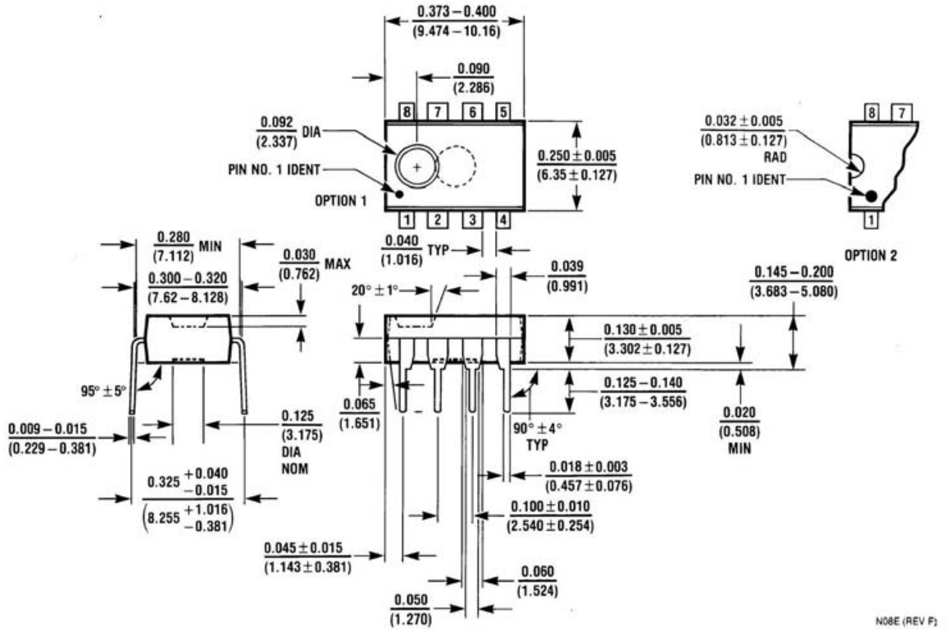


8-Lead Ceramic Dual-In-Line Package
Order Number LM6172AMJ-QML or 5962-9560401QPA
NS Package Number J08A



8-Lead (0.150" Wide) Molded Small Outline Package, JEDEC
Order Number LM6172IM or LM6172IMX
NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



8-Lead (0.300" Wide) Molded Dual-In-Line Package
Order Number LM6172IN
NS Package Number N08E

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Appendix 3:

Data sheet of Photomultiplier R5900-00-M4 (Hamamatsu)

HAMAMATSU

PRELIMINARY DATA

MAR. 1997

MULTIANODE PHOTOMULTIPLIER TUBE R5900U-00-M4

FEATURES

- 2 × 2 multianode
- Newly developed "metal channel dynode"
- High speed response
- Low cross - talk

GENERAL

Parameter		Description / Value	Unit
Spectral Response		300 to 650	nm
Wavelength of Maximum Response		420	nm
Photocathode	Material	Bialkali	–
	Minimum Effective Area	18 × 18	mm^2
Window Material		Borosilicate glass	–
Dynode	Structure	Metal channel dynode	–
	Number of Stages	10	–
Weight		Approx. 26	g
Suitable Socket		E678-32B (option)	–

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter		Value	Unit
Supply Voltage	Between Anode and Cathode	900	Vdc
Average Anode Current		0.1	mA

CHARACTERISTICS (at 25 °C)

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856 K)	50	70	–	μA/lm
	Blue (CS - 5 - 58 filter)	6	8	–	μA/lm-b
Anode Sensitivity	Luminous (2856 K)	25	140	–	A/lm
Gain		5×10^5	2×10^6	–	–
Anode Dark Current per Channel (after 30min. storage in darkness)		–	0.5	–	nA
Time Response	Anode Pulse Rise Time	–	1.2	–	ns
	Transit Time Spread (FWHM)	–	0.32	–	ns
Pulse Linearity per Channel (± 2 % deviation)		–	5(30ⓐ)	–	mA
Cross - talk (9 × 9 mm^2 Aperture)		–	2	4	%
Uniformity Between Each Anode		–	1:1.5	1:3	–

NOTE : Anode characteristics are measured with the voltage distribution ration A shown below.

ⓐ : Measured with the special voltage distribution ratio B (Tapered Bleeder) shown below.

VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

Electrodes	K	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	P
Ratio A	1.5	1.5	1.5	1	1	1	1	1	1	1	1	
Ratio B (Tapered Bleeder)	1.5	1.5	1.5	1	1	1	1	1	1	2	3.6	

Supply Voltage: 800 Vdc, K: Cathode, Dy: Dynode, P: Anode

MULTIANODE PHOTOMULTIPLIER TUBE R5900U-00-M4

Figure 1: Typical Spectral Response

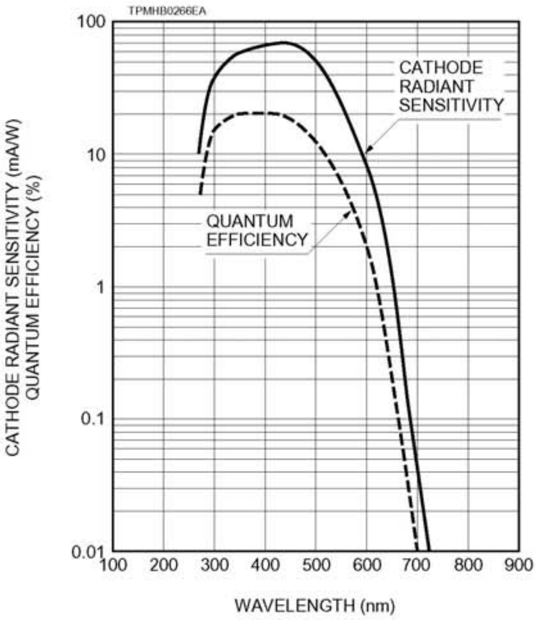


Figure 2: Typical Gain and Anode Dark Current

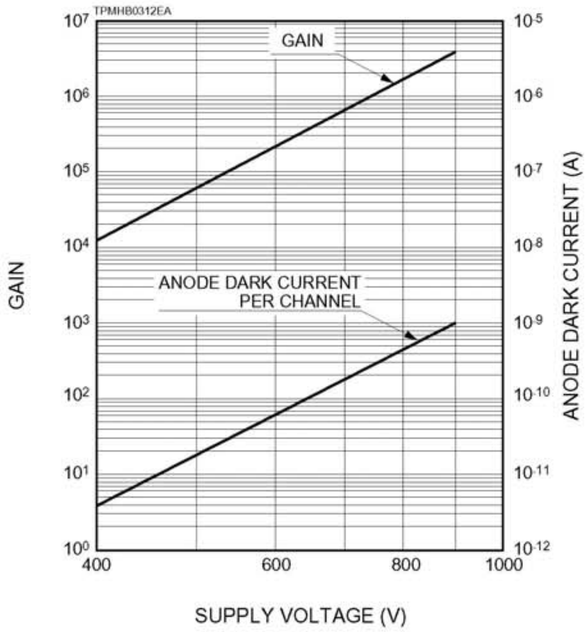


Figure 3: Typical Time Response

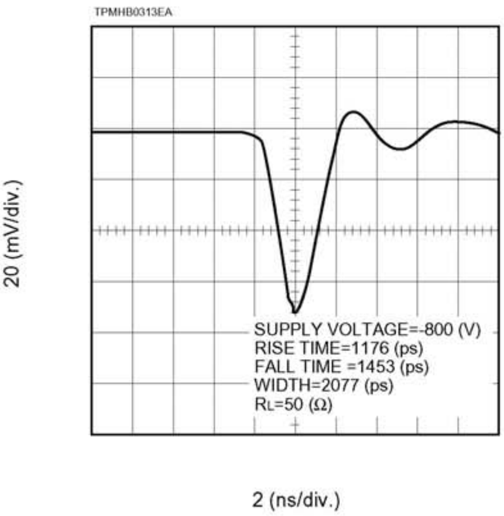


Figure 4: Typical T.T.S. Characteristic

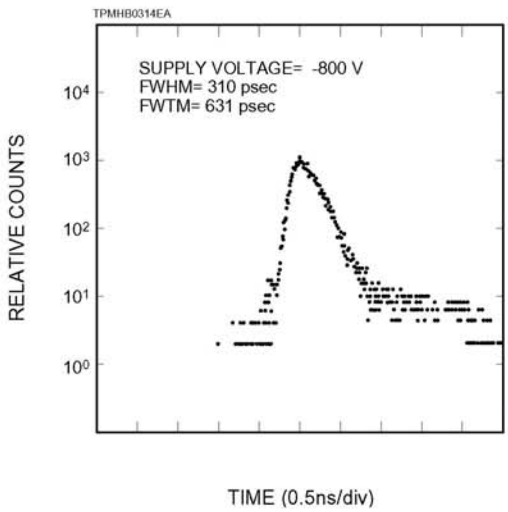


Figure 5: Pulse Linearity per Channel

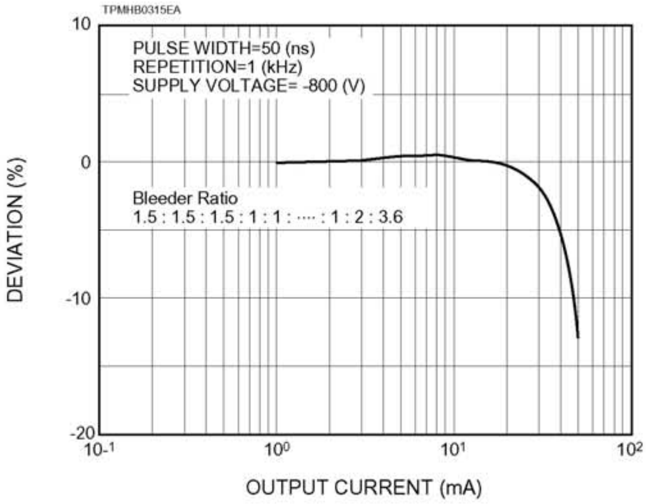


Figure 6: Anode Uniformity (Example)

82	95
97	100

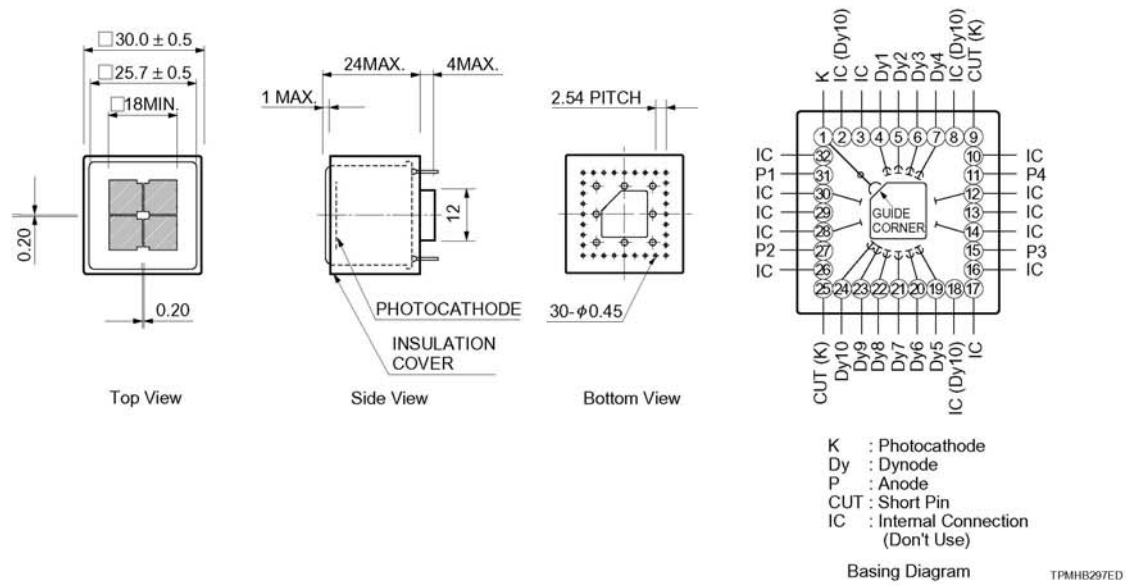
Supply Voltage : 800 V
Light Source : Lamp(uniform DC light)
Full Illumination

Figure 7: Anode Cross Talk (Example)

0.1	0.9
1.3	100

Supply Voltage : 800 V
Light Source : Lamp(uniform DC light)
Spot Illumination : 9 × 9 mm²

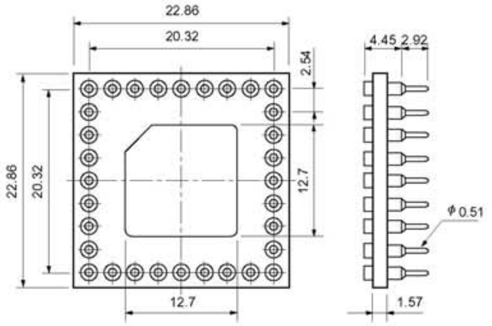
Figure 8: Dimensional Outline and Basing Diagram (Unit: mm)



MULTIANODE PHOTOMULTIPLIER TUBE R5900U-00-M4

[ACCESSORIES]

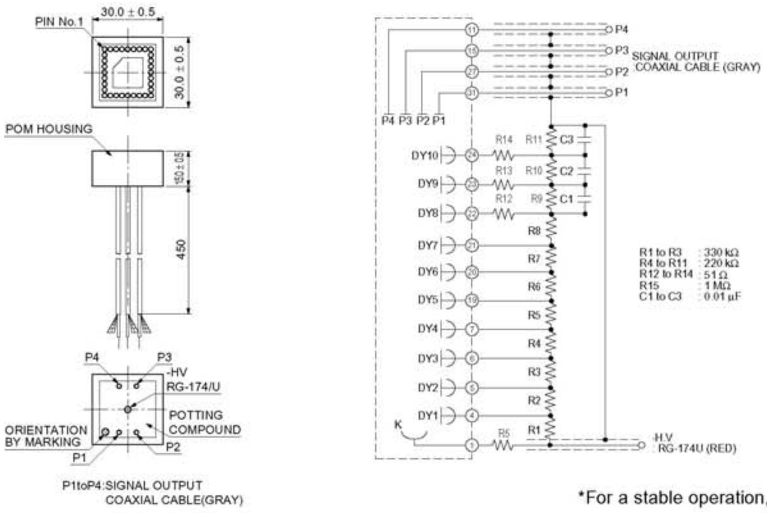
● Socket E678-32B [OPTION]



MATERIAL: Glass Epoxy

TACCA0094ED

● D Type Socket Assembly E7083



*For a stable operation, all of anodes should be connected to ground potential through load resistors such as 100 k ohm or so, even if they are not used.

TACCA0162EA

⚠ WARNING ~ High Voltage ~

The product is operated at high voltage potential. Further, the metal housing of the product is connected to the photocathode (potential) so that it becomes a high voltage potential when the product is operated at a negative high voltage (anode grounded).
Accordingly, extreme safety care must be taken for the electrical shock hazard to the operator or the damage to the other instruments.

* PATENT: USA Pat. No. 5410211 PATENT PENDING: JAPAN11, USA1, EUROPE2

HAMAMATSU

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Germany: Hamamatsu Photonics Deutschland GmbH: Arzbergerstr. 10, D-82211 Herrsching am Ammersee, Germany, Telephone:(49)8152-375-0, Fax:(49)8152-2658
France: Hamamatsu Photonics France: S.A.R.L.: 8, Rue du Saule Trapu, Parc du Moulin de Massy, 91882 Massy Cedex, France, Telephone:(33)1 69 53 71 00, Fax:(33)1 69 53 71 10
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